Front cover photo: A valley fill and sediment-control pond in the Ballard Fork Watershed, West Virginia.

Back cover photo: Ballard Fork near Mud, West Virginia.

U.S. Department of the Interior
U.S. Geological Survey

Relations Between Precipitation and Daily and Monthly Mean Flows in Gaged, Unmined and Valley-Filled Watersheds, Ballard Fork, West Virginia, 1999–2001

TERENCE MESSINGER and KATHERINE S. PAYBINS

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CONVERSION FACTORS

Multiply	By	To Obtain
acre	4,047	square meter (m^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer ($m^3/s/km^2$)
cubic foot per second per inch per square mile [(ft^3/s)/in/mi^2]	0.0004305	cubic meter per second per centimeter per square kilometer ($m^3/s/cm/km^2$)
foot (ft)	0.3048	meter (m)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
short ton (t)	907.2	kilogram (kg)
square mile (mi^2)	2.590	square kilometer (km^2)

DATUMS

In this report, vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) and horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Historical data collected and stored as National Geodetic Vertical Datum of 1929 have been converted to North American Vertical Datum of 1988 (NAVD 88) for this publication.

Relations Between Precipitation and Daily and Monthly Mean Flows in Gaged, Unmined and Valley-Filled Watersheds, Ballard Fork, West Virginia, 1999–2001

By Terence Messinger *and* Katherine S. Paybins

ABSTRACT

Large-scale surface mining using valley fills has changed hydrologic storage and processes in the Ballard Fork Watershed in West Virginia. Total unit flow for the 2-year study period (November 15, 1999–November 14, 2001) on the Unnamed Tributary (extensively mined) (11,700 cubic feet per second per square mile) was almost twice that on Spring Branch (unmined) (6,260 cubic feet per second per square mile), and about 1.75 times that on Ballard Fork (downstream, partly mined) (6,690 cubic feet per second per square mile). Unit flow from the Unnamed Tributary exceeded that from the other two streams for all flows analyzed (5–95 percent duration). Unit flow from Ballard Fork exceeded unit flow from Spring Branch about 80 percent of the time, but was about the same for high flows (less than 20 percent duration). The proportional differences among sites were greatest at low flows. Spring Branch was dry for several days in October and November 2000 and for most of October 2001, and the Unnamed Tributary had flow throughout the study period.

The increase in flows from mined parts of the Ballard Fork Watershed appears to result from decreases in evapotranspiration caused by removal of trees and soil during mining. During both years, evapotranspiration from the Spring Branch Watershed greatly exceeded that from the Unnamed Tributary Watershed during May through October, when leaves were open. Evapotranspiration from the Unnamed Tributary Watershed slightly exceeded that from the Spring Branch Watershed in February and March during both years. Evapotranspiration, as a percentage of total rainfall, decreased from the first to the second, drier, year from the Unnamed Tributary Watershed (from 61 percent to 49 percent) but changed little from the Spring Branch (from 77 to 76 percent) and Ballard Fork (73 to 76 percent) Watersheds.

Precipitation and flow during the study period at three nearby long-term sites, the U.S. Geological Survey stream-gaging station East Fork Twelvepole Creek near Dunlow, West Virginia, and two National Oceanic Atmospheric Administration rain gages at Madison and Dunlow, West Virginia, were less than long-term annual averages. Relations observed among the three streams in the Ballard Fork Watershed during this study may not represent those in years when annual precipitation and flow are closer to long-term averages.

INTRODUCTION

Mountaintop-removal and other large surface mines that dispose of spoil in valley fills (fig. 1) have become increasingly controversial in the central Appalachians since the mid-1990s (Loeb, 1997; Bragg v. Robertson, Civil Action No. 2:98-636 [S.D. W.Va.]). As a condition of a partial settlement of Bragg v. Robertson, federal agencies with regulatory jurisdiction over coal mining were required to prepare a comprehensive Environmental Impact Statement (EIS) on the effects of valley fills. As part of that effort, the U.S. Geological Survey (USGS), in cooperation with the Office of Surface Mining, Regulation, and Enforcement, began a study of relations between flow and precipitation in mined and unmined parts of the Ballard Fork Watershed, in the upper Mud River Basin, in November 1999 (fig. 2).

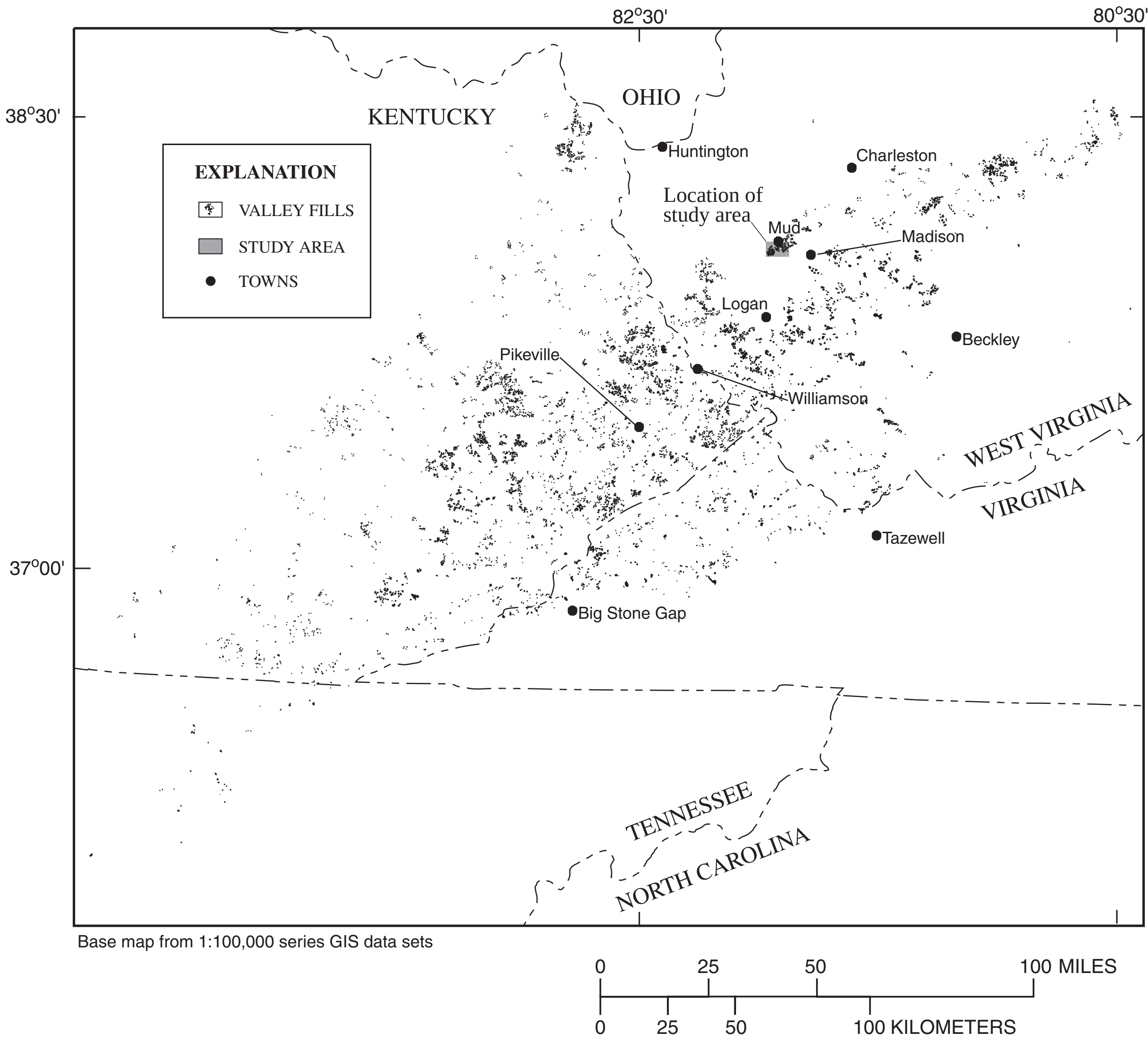
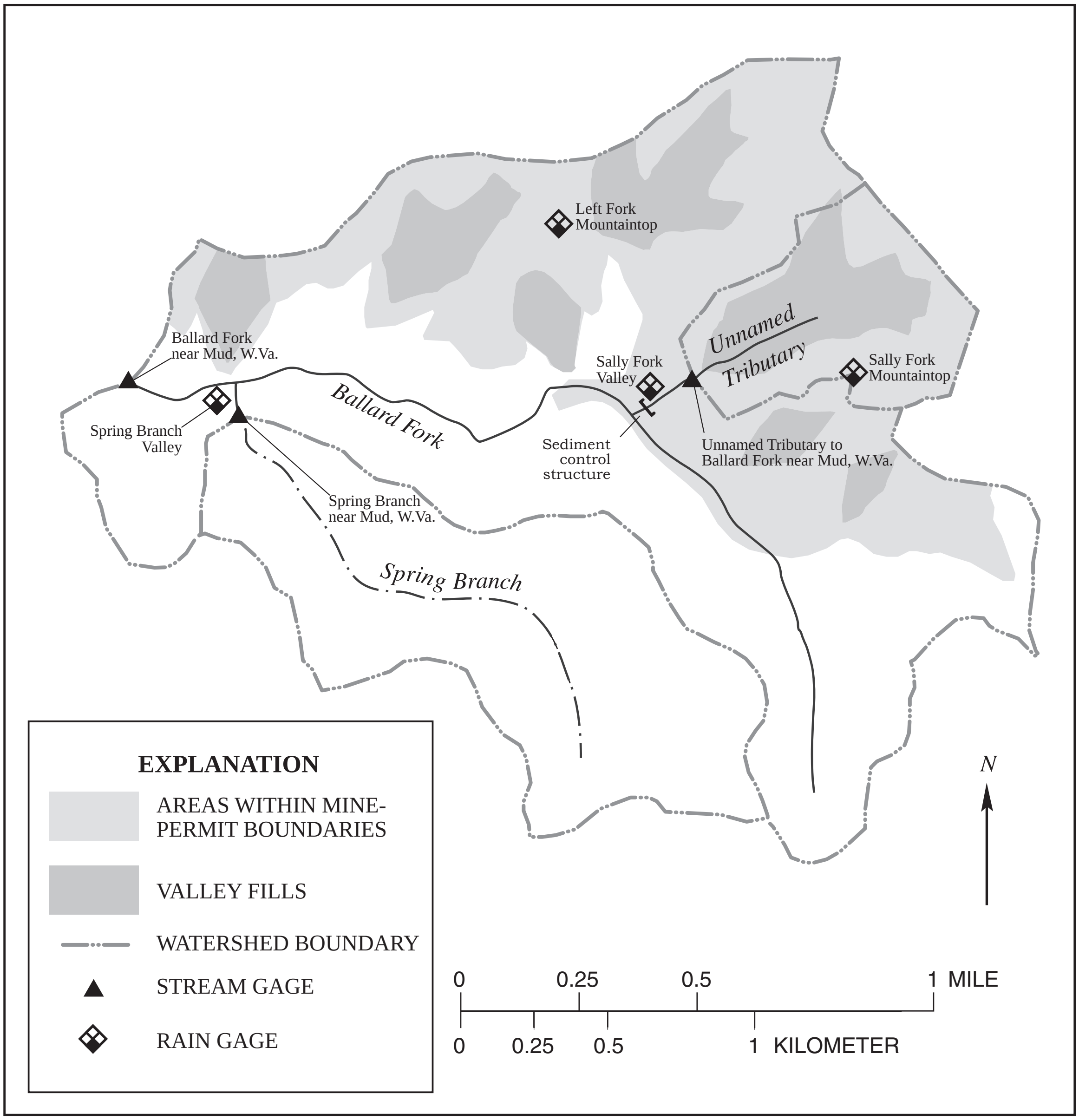


Figure 1. Valley fills in the Central Appalachian coal field and location of the Ballard Fork Watershed, West Virginia.



Modified from U.S. Environmental Protection Agency and
West Virginia Department of Environmental Protection digital data

Figure 2. Streams, stream-gaging stations, rain gages, valley fills, and areas permitted for mining in the Ballard Fork Watershed, West Virginia.

Surface mining is an important method of extracting coal in the low-sulfur Central Appalachian Coal Field of southern West Virginia, southwestern Virginia, eastern Kentucky, and northeastern Tennessee. During 1996–2000, more than 1.36 billion tons of coal were mined from this coal field—25 percent of all coal mined in the United States (Energy Information Administration, 2002). In 2000, more than 258 million tons of coal were surface mined in this coal field; this production accounted for 42 percent of the coal mined in the coal field by all methods and 10 percent of the coal mined in the United States.

During the 1990s, production of the mostly low-sulfur coal from this coal field has increased, a trend that is widely attributed to provisions in the Clean Air Act amendments of 1991 that were intended to reduce acid precipitation (Messinger and Hughes, 2001). Surface mining has increased steadily during the same period, because increases in the size and efficiency of earth-moving equipment made it profitable to mine multiple thin coal seams covered by hundreds of feet of rock. In mountaintop removal mines and other large surface mines, rock is removed from the tops of mountains and dumped in "valley fills" in adjacent headwater valleys.

Purpose and Scope

The purpose of this report is to describe and compare stream characteristics measured on three small gaged watersheds in the Ballard Fork Watershed, in the mountaintop-removal coal mining region of southern West Virginia, between November 15, 1999, and November 14, 2001. The scope of this report is limited to stream characteristics that respond to precipitation over a period of 1 or more days, measured as daily mean flow. Another report produced in this study discusses short-term (less than 1 day) flow response of the same three streams to storms (Messinger, 2003). This study was done as part of the programmatic Environmental Impact Statement on valley fills.

Description of Study Area

The study area is in the Kanawha Section of the Appalachian Plateaus Physiographic Province (Fenneman, 1938). Surface rocks are sedimentary and of Pennsylvanian age (Cardwell and others, 1968). The closest long-term climatography station, in Madison, WV, receives an average of 47.7 in. of precipitation annually (1971–2000) (National Oceanic and Atmospheric Administration, 2002). Madison receives an average of 17.5 in. of snow per year (1971–2000). July is the wettest month, with an average precipitation of 4.88 in.

Flow in southern West Virginia streams is dominated by rainfall, even during the winter. Long-term average flows are greatest in February through April, the period of maximum soil-moisture and ground-water recharge for the year, and are least in September and October, the period of lowest precipitation for the year (Messinger and Hughes, 2001). Long-term average maximum precipitation is received during May through July, and coincides with the period of maximum evapotranspiration. Most precipitation in winter results from passage of fronts and usually comes as slow, soaking rains throughout the region. Most precipitation in summer results from thunderstorms, which are often short, intense, and localized.

Three stream-gaging stations were sited to address the effects of mining, particularly valley fills, on flow (fig. 2). One stream-gaging station was installed on an Unnamed Tributary to Ballard Fork directly downstream from a valley fill and upstream from a sediment pond. The Unnamed Tributary drains 0.19 mi^2 at the stream-gaging station, all of which is within the area permitted for mining, including 0.084 mi^2 (44 percent) covered by the single valley fill in the watershed. A small area (less than 5 acres, or 0.008 mi^2) immediately uphill from the Unnamed Tributary stream-gaging station was not disturbed by mining. The second stream-gaging station was installed near the mouth of Spring Branch, which drains an unmined watershed. Spring Branch drains 0.53 mi^2 at the stream-gaging station. The third stream-gaging station was installed on the main stem of Ballard Fork about 0.3 mi downstream from the confluence with Spring Branch. Ballard Fork drains 2.19 mi^2 at the stream-gaging station. About 0.26 mi^2 (12 percent) of the Ballard Fork Watershed was covered by seven valley fills, and about 0.89 mi^2 (40 percent) was permitted for mining, although not all the permitted area was actually mined. Because regulations prohibit damage resulting from mining activities outside the permitted area, it is standard practice for permits to include a buffer area. All valley fills in the Ballard Fork Watershed were built by dumping overburden from trucks over the edge of the bench (or fill) into the valley. The sediment ponds for the mines were still in place during this study. All mine runoff flowing past the Ballard Fork stream-gaging station had previously flowed through a sediment pond; this condition is normal for streams receiving runoff from active mines.

All mining in the Ballard Fork Watershed had been done under a single permit issued in 1989; unlike most nearby mined areas, the study area has no recorded deep mines, which can affect flow in a variety of ways and therefore complicate determining the effect of surface mining on flow. The mine permit specified a post-mining land use of rangeland. No coal was mined in the watershed during this study. The mine was still under reclamation in October 1999, although mine-inspection forms showed that inspectors had estimated that no more than ten acres were unreclaimed by November 1997 (West Virginia Department of Environmental Protection, 2003). The mine received a partial ("Phase 1") bond release in August 2000, when backfilling and grading had been satisfactorily completed. Activities that sometimes take place during this stage of reclamation include installing drainage structures and moving backfill material, both of which would affect rainfall-runoff relations.

The coal seams mined in the Ballard Fork Watershed were at the base of the Allegheny Formation, and the overburden was from rocks of that formation and the next major map unit upward, the Conemaugh Group (Cardwell and others, 1968). The Allegheny Formation and Conemaugh Group are both Pennsylvanian. The Allegheny Formation is mixed sandstone, shale, siltstone, and coal, and the Conemaugh Group is predominantly shale with some interbedded sandstone and siltstone. The sandstones of both these units are typically soft and crumbly and weather rapidly when exposed. Mine spoil from these rocks is expected to produce abundant fine particles, which would in turn fill some of the void space in the fill and lead to channelized flows of the type observed in other valley fills (Hawkins, 1998). The Kanawha Formation, which is Pennsylvanian, is predominantly hard, massive sandstone with some interbedded shale, is beneath the base of the Allegheny Formation, and forms the bottoms of mountains and underlies the valley floor.

The Ballard Fork Watershed had no human residents during the study period, and the unmined parts of the watershed were predominantly forest. However, the unmined parts of the watershed were not pristine. Several roads passed through the unmined parts of the watershed, and many or most of these roads had rills and gullies which could affect rainfall-runoff relations. Natural gas wells and pipelines have also been built in unmined parts of the watershed. Some of the pipeline rights-of-way have been used as all-terrain vehicle trails. Steep sections of these trails are extensively gullied and eroded, as are similar sections of all-terrain vehicle trails in the mined part of the watershed.

Forest in the Spring Branch Watershed and other unmined parts of the Ballard Fork Watershed is second- or third-growth. Common canopy species include white and red oak, several hickory species, sycamore, and tulip poplar. The understory includes dogwoods, redbuds, and saplings of typical canopy species. No large forest fires took place during the study period, and leaf litter was present on the forest floor. In the mined parts of the Ballard Fork Watershed, vegetation was sparse and included broomsedge and other grasses, crown vetch, and other herbaceous vegetation typical of dry and disturbed land, as well as scattered woody vegetation that included autumn olive, tree of heaven, and white pine. Revegetation in the mined areas was ongoing but incomplete during the study period. Soil-survey information was not available for the mined areas, but field reconnaissance showed that the soils were generally thin and stony.

The Unnamed Tributary flows generally southwest (fig. 2). Its watershed has a maximum length of 3,250 ft, and maximum width of 2,500 ft. Spring Branch flows generally northwest. The maximum length of its watershed is 7,500 ft, and maximum width is 3,000 ft. Ballard Fork flows generally west. The maximum length of its watershed is 10,500 ft, and maximum width is 9,500 ft. Storms in the region typically move from west to east, so that under normal conditions, the downstream parts of the watersheds receive precipitation before the upland areas. Basin relief at the time of the study was measured from a topographic map as 680 ft in the Spring Branch Watershed and 700 ft in the Ballard Fork Watershed. Post-mining basin relief in the Unnamed Tributary Watershed was measured as about 450 ft from altimeter readings taken at some of the highest points in the watershed.

Study Design and Data Collection

Data were collected for this study from November 15, 1999, through November 14, 2001, a time referred to in this report as the "study period;" November 1999 through November 2000 is referred to as the "first year of the study," and November 2000 through November 2001 is referred to as the "second year of the study." All rain gages and stream-gaging stations are in West Virginia.

Three stream-gaging stations for continuous flow measurement were installed by the USGS in November 1999 in the Ballard Fork Watershed near Madison (figs. 1, 2). Continuous stage data were collected and flow records were computed according to procedures described by Rantz and others (1982). Part of the data-processing and compilation process is an assessment of data quality. Records are assessed as excellent, good, fair, or poor, if about 95 percent of the data are within 5, 10, 15, or more than 15 percent, respectively, of the true flow value. This assessment is included in station manuscripts in the USGS series of annual Water-Resources Data Reports (Ward and others, 2001; 2002). Data-quality assessments are based on factors including stage-sensor response, stability of the stage-discharge relationship, and completeness of the record. In this report, when the phrase "measurement error" is used in reference to daily-discharge data or data derived from daily-discharge data, it refers to these data-quality assessments. Published data include estimates of daily mean flow for periods when the stage record is lost because of instrument malfunction; these estimates are identified in Water-Resources Data Reports. Estimates are made on the basis of comparison of hydrographs between nearby stream-gaging stations, or regression of flow records between stream-gaging stations with correlated records.

Four rain gages were installed in the Ballard Fork Watershed during this study to collect precipitation data in 10-minute intervals (fig. 2). Two were on mountaintops (Sally Fork Mountaintop Rain Gage and Left Fork Mountaintop Rain Gage) and two were on the valley floor (Sally Fork Valley Rain Gage and Spring Branch Valley Rain Gage). Although there was usually variation in the amount and timing of rainfall recorded by the four rain gages, when all four rain gages functioned properly, recorded rainfall was within the range of variation expected to result from random causes among rain gages receiving the same amount of rain (Black, 1996). In this report, rainfall totals at the watershed scale are assumed to be the same throughout the Ballard Fork Watershed, and rainfall averaged from all functioning rain gages was assumed to have fallen throughout the watershed.

Watershed boundaries were delineated on a 1:24,000 USGS topographic map for the unmined part of the watershed. Mining changed the topographic boundary of the watershed in the mined areas, and a post-mining topographic map was not available. The post-mining topographic perimeter was mapped by use of a Global Positioning System (GPS) at locations determined in the field. A watershed boundary based on topography might not be accurate, particularly where it crosses the valley fill, because water can flow along subsurface confining layers into or out of a watershed. Watershed boundaries based on topography were used in this study, however, because of the uncertainties with respect to subsurface flows.

Hydrologic Conditions from 1999 through 2001

Hydrologic conditions during the study period at three nearby long-term sites, the USGS stream-gaging station East Fork Twelvepole Creek near Dunlow and two National Oceanic Atmospheric Administration (NOAA) rain gages at Madison and Dunlow (fig. 3) were not representative of long-term conditions. In 2000, total precipitation was close to long-term averages (47.8 and 45.7 in., respectively, 1971–2000) at both Madison and Dunlow (46.2 and 47.4 in., respectively). Total precipitation was substantially less than average in 2001 (40.2 and 35.0 in., respectively) (National Climatic Data Center, 2002). More important than deviation from the annual totals, however, was timing and intensity of precipitation, which was unusual in both years.

Total precipitation for the study period was nearly the same at Dunlow (78.6 in.) and in the Ballard Fork Watershed (78.4 in. mean). Ballard Fork received substantially more rain than Dunlow in a few storms (most notably from several-day storm systems during February 2000 and May and July 2001), and Dunlow received substantially more rain than Ballard Fork in at least one storm (during July 2000).

Average flow in East Fork Twelvepole Creek near Dunlow was substantially less than the long-term average flow (52.0 ft^3/s) in the 2000 and 2001 water years (29.6 ft^3/s in 2000, and 21.6 ft^3/s in 2001) (Ward and others, 2001; Ward and others, 2002). Below-average flow is to be expected for 2001, a year with below-average

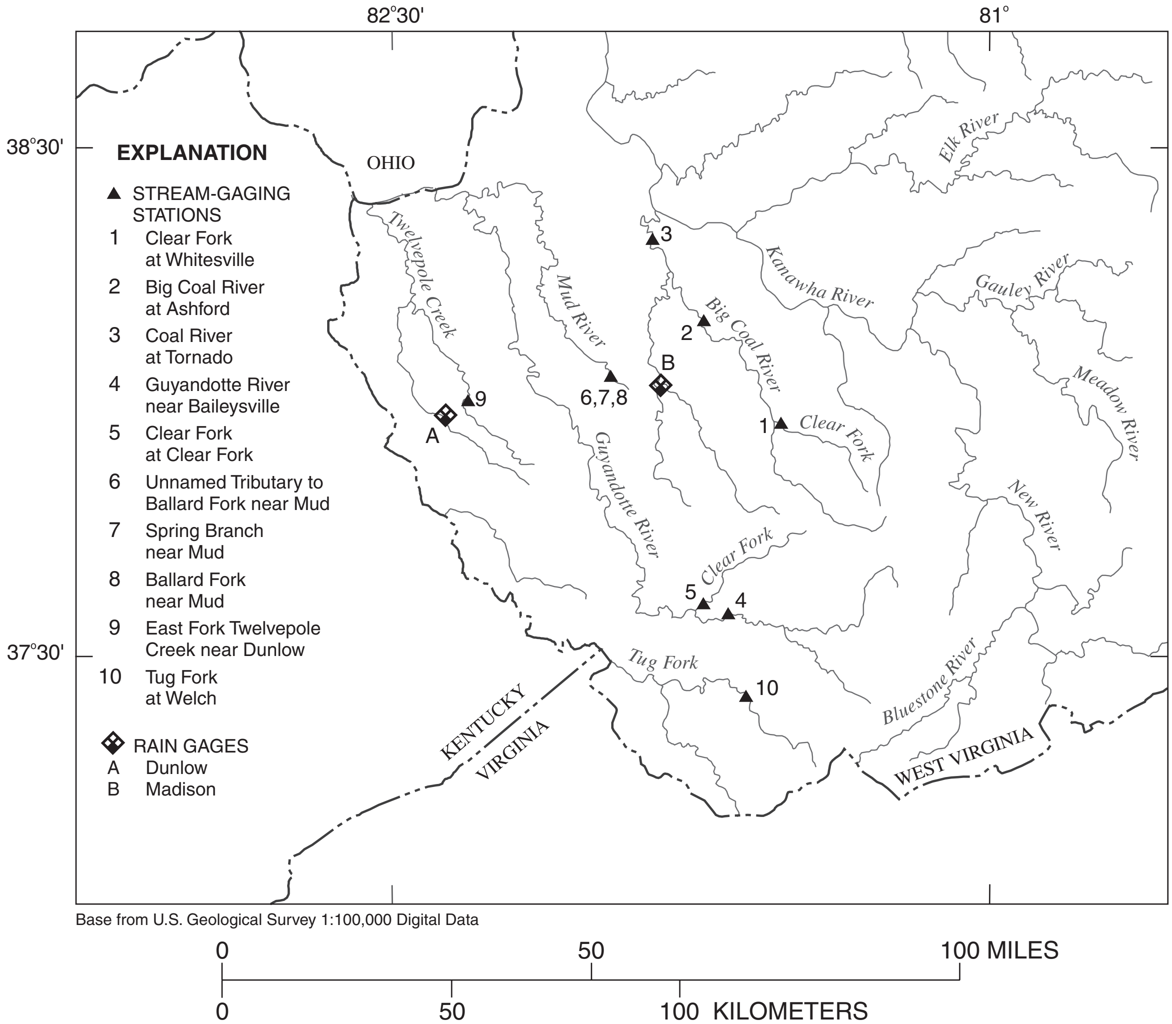


Figure 3. Selected streams, stream-gaging stations, and rain gages in southern West Virginia.

precipitation, but is surprising for 2000, a year with near-average precipitation. The relation between flow in 2000 and the long-term average at Dunlow was similar to that at other gaged sites in southern West Virginia (table 1).

The incongruity of near-average precipitation resulting in low flow in 2000 was caused by seasonal distribution of precipitation (table 2). Precipitation at Madison was 4.71 in. below average from November 1999 through March 2000, typically the period of maximum recharge and runoff. Recharge of aquifers and soil moisture during winter and early spring typically sustains base flow throughout the year. In 2000, precipitation at Madison exceeded the long-term average during June and July, the period of maximum evapotranspiration, by 4.82 in. Much of this excess precipitation was intercepted or transpired by trees, or recharged soil moisture, and was unavailable to run off to streams.

The second year of the study, 2001, was dry. The annual totals for precipitation and flow conceal the overall dryness of the year, because 11.41 in. of rain in the Ballard Fork Watershed, 32 percent of the total for the year, fell during two storms, one during May 16–22 and one during July 26–29. Ballard Fork received only 0.65 in. of rain from the July 8, 2001, storm (table 4, at back of report) that caused heavy flooding throughout much of southern West Virginia (West Virginia Department of Environmental Protection, Flood Advisory Task Force, 2002).

Table 1. Average streamflow for water year 2000 and period of record for selected stream-gaging stations in southern West Virginia

[WY, water year, or the period from October 1 through September 30 of the following year. ft^3/s, cubic feet per second; mi^2, square miles]

Stream gage	Station No.	Period of record	Drainage area (mi^2)	Long-term average (ft^3/s)	WY 2000 average (ft^3/s)
Big Coal River at Ashford	03198500	1908–16, 1930–present	391	522	402
Coal River at Tornado	03200500	1908–11, 1911–12,1928–31, 1961–present	862	1,203	891
Guyandotte River near Baileysville	03202400	1968–present	306	415	313
Clear Fork at Clear Fork	03202750	1974–present	126	191	166
East Fork Twelvepole Creek near Dunlow	03206600	1964–present	38.5	52.0	29.6
Tug Fork at Welch	03212750	1985–93, 1996–present	174	192	132

During the study period, lowest flows were during the fall, and peaks followed storm precipitation (fig. 4). The streams in the Ballard Fork Watershed responded differently to storms; unit peak flow from the Spring Branch Watershed exceeded that from the Unnamed Tributary Watershed after soaking rains, particularly in winter, but unit peak flow from the Unnamed Tributary Watershed exceeded that from the Spring Branch Watershed after summer thunderstorms when rainfall intensity exceeded about 1 in. per hour (Messinger, 2003). As noted in the precipitation discussion, storms differed somewhat between Dunlow and the Ballard Fork Watershed. As a result, peak flows differed between East Fork Twelvepole Creek near Dunlow and the streams in the Ballard Fork Watershed (fig. 4). Dry periods in the two basins generally coincided.

Monthly flow patterns were different among the three streams in the Ballard Fork Watershed during the study period (fig. 5). At all sites, the lowest flows sustained for several days were during fall months, although unit low flows on the Unnamed Tributary were much higher (more than double) than unit low flows on Spring Branch and Ballard Fork. The highest unit monthly flow in the study period in Ballard Fork was during May 2001, because of a series of thunderstorms that produced 6.22 in. of rain in eight days (May 15–22). The flow record for Spring Branch was lost during this period because of a stage-sensor malfunction; but on the basis of hydrographic comparison and regression with the flow record from Ballard Fork, flow at Spring Branch during May 2001 was estimated to be the highest monthly total during the study period. Monthly total flows in these streams dropped for the rest of the summer and fall, although both streams had major peaks during that period (figs. 4, 5). The maximum total monthly flow on the Unnamed Tributary was in June 2001, although total monthly flow varied little during May through July 2001. Differences between total monthly unit flow in Spring Branch and Ballard Fork were usually less than the measurement error, except during the summer, when unit flows in Ballard Fork were somewhat higher. Total unit flow for the 2-year study period on the Unnamed Tributary (11,700 $ft^3/s/mi^2$) was almost twice that on Spring Branch (6,260 $ft^3/s/mi^2$), and about 1.75 times that on Ballard Fork (6,690 $ft^3/s/mi^2$).

Acknowledgments

The authors thank John McDaniel and the Arch Coal Corporation, who have been helpful during the course of this work. Robert Bragg and Freddie Brogan, of the U.S. Geological Survey in Charleston, did most of the field work during this study.

Table 2. Long-term average and study-period total monthly precipitation, in inches, for Ballard Fork Watershed, Dunlow and Madison, West Virginia

[Data for Dunlow and Madison are from the National Oceanic and Atmospheric Administration, 2002. ≥, greater than or equal to; --, not presented]

Site	January	February	March	April	May	June	July	August	September	October	November	December
Ballard Fork Watershed, 1999	--	--	--	--	--	--	--	--	--	--	4.37	2.87
Ballard Fork Watershed, 2000	1.41	3.22	2.44	4.14	4.93	6.34	5.37	4.21	2.90	0.56	1.18	2.45
Ballard Fork Watershed, 2001	2.49	2.31	2.84	1.59	7.13	3.69	8.33	2.74	2.35	1.29	--	--
Dunlow, 1999	--	--	--	--	--	--	--	--	--	--	3.59	≥2.03
Dunlow, 2000	≥1.92	≥2.90	2.91	4.99	3.97	6.34	7.27	3.53	3.59	.51	1.31	≥2.89
Dunlow, 2001	≥2.58	≥2.82	≥3.01	2.00	5.55	3.56	5.21	3.35	1.29	1.45	--	--
Dunlow, 1971–2000	3.30	3.21	3.88	3.77	4.92	4.20	4.74	3.83	3.39	2.98	3.73	3.76
Madison, 1999	--	--	--	--	--	--	--	--	--	--	4.21	≥1.86
Madison, 2000	1.59	≥3.38	2.54	3.95	4.77	7.52	7.05	5.42	3.05	.84	1.41	≥2.16
Madison, 2001	2.36	2.46	3.11	≥2.12	7.45	4.53	9.18	1.91	1.93	1.61	--	--
Madison, 1971–2000	3.47	3.21	3.92	3.90	5.17	4.58	5.17	4.58	3.71	2.91	3.59	3.63

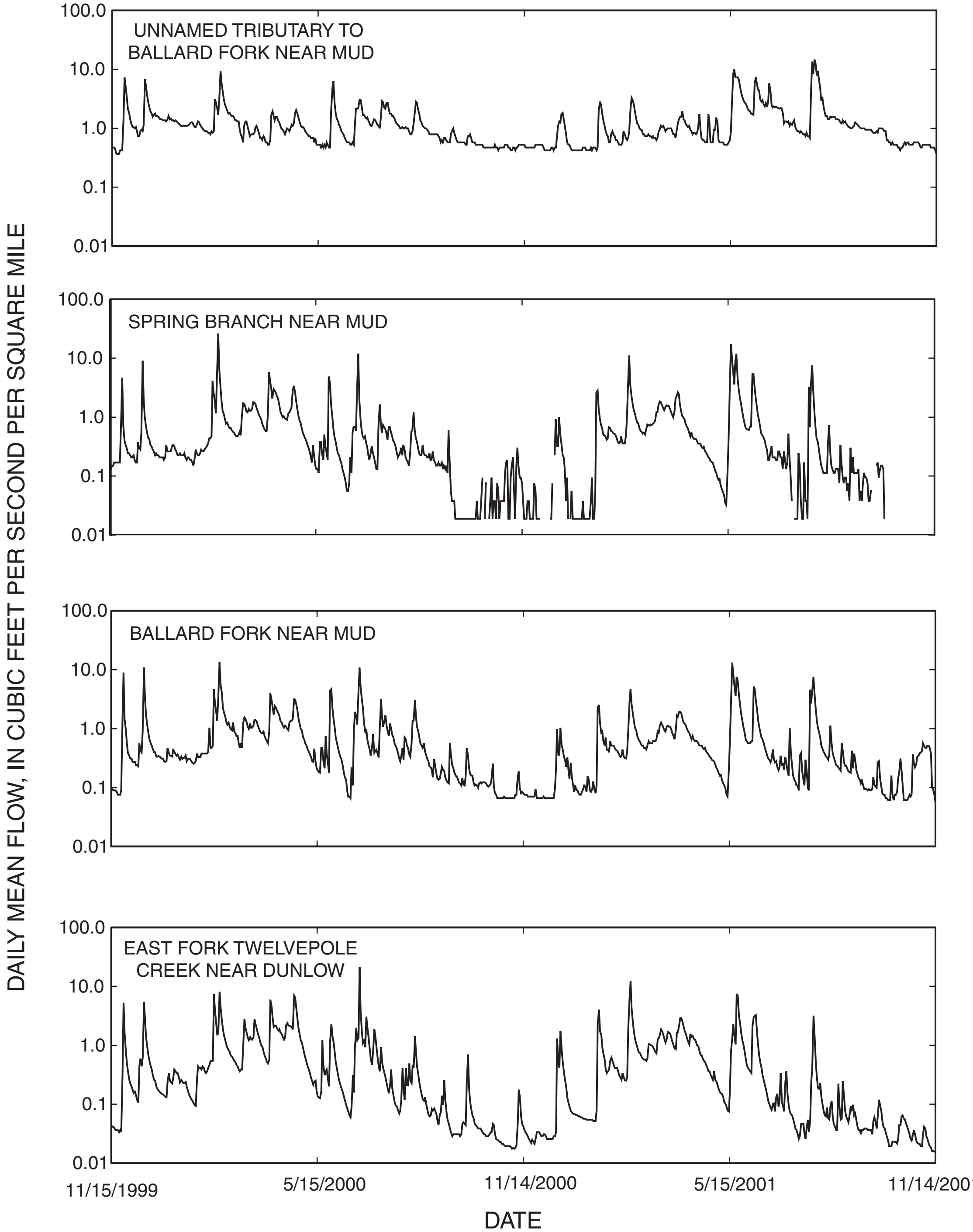


Figure 4. Hydrographs for three streams in the Ballard Fork Watershed and the index site, East Fork Twelvepole Creek near Dunlow, West Virginia, November 15, 1999–November 14, 2001. Values of zero flow are not shown.

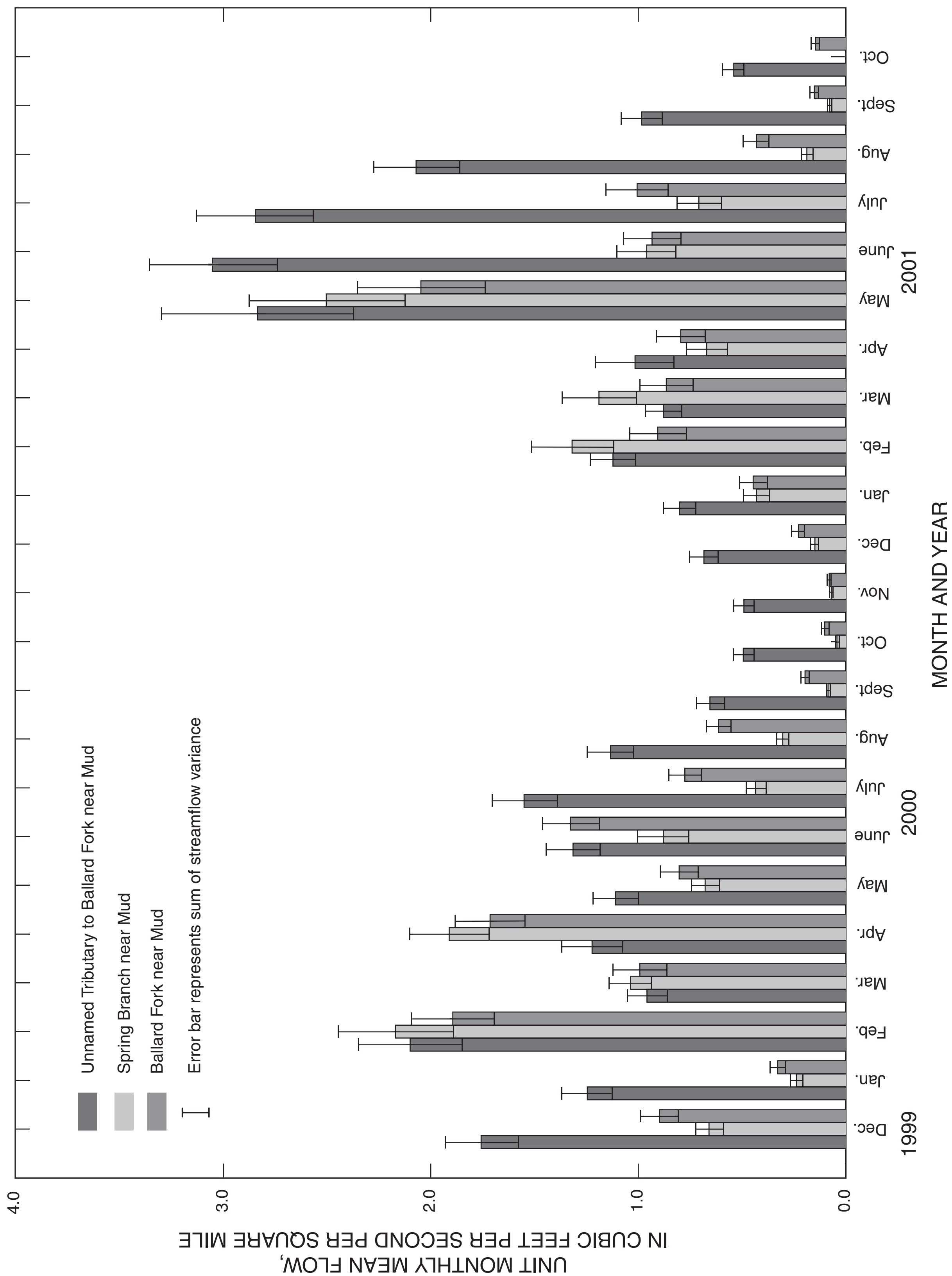


Figure 5. Unit monthly mean flow for three sites in the Ballard Fork Watershed, West Virginia, 1999–2001. Error bars represent the sum of daily-mean streamflow variance determined from estimates of daily quality made by Ward and others (2001, 2002). Spring Branch had average flow of zero during October 2001.

RELATIONS BETWEEN PRECIPITATION AND FLOW IN UNMINED AND VALLEY-FILLED WATERSHEDS

Hydrologic characteristics of the Ballard Fork Watershed during the study period were affected by watershed characteristics. The principal difference among the watersheds in the study area was in the extent of coal mining. This affected stream and watershed characteristics including the relation of daily and monthly flow among sites, evapotranspiration, flow duration, flow variability, and stream response to storms.

Relation of Flow Among Sites and with Long-Term Stream-Gaging Stations

Most factors that influence flow characteristics are regional in nature, so that flow characteristics at nearby sites are usually correlated (Black, 1996). Stream-gaging stations with short periods of record are routinely compared to nearby index stream-gaging stations with longer periods of record, to assess how representative the period of record is at the short-term site and to estimate some flow statistics that usually require a long period of record to determine. An index site should have basin characteristics similar to those of the short-term site. In this report, comparisons are made between streamflow at the stream-gaging stations in the Ballard Fork Watershed and in the East Fork of Twelvepole Creek, and between rainfall in the Ballard Fork Watershed and at Madison and Dunlow. In addition, some flow characteristics are estimated for streams in the Ballard Fork Watershed by comparison to flow characteristics of the East Fork of Twelvepole Creek.

Assessing the relation between the index site and the study sites requires assessing the relation among the study sites. Log-transformed daily mean flow for the study period was significantly ($p < 0.01$) correlated between all pairs of the three streams in the Ballard Fork Watershed. Estimated values were excluded from this analysis because they were obtained by comparison and regression of flow records among the three stream-gaging stations, and observations of zero flow were excluded because they could not be log-transformed. The correlation was strongest between Spring Branch and Ballard Fork ($R^2 = 0.813$), second strongest between the Unnamed Tributary and Ballard Fork ($R^2 = 0.578$), and weakest between the Unnamed Tributary and Spring Branch ($R^2 = 0.406$) (fig. 6). Correlation of daily flow between nearby sites is sometimes affected by differences in timing of runoff among streams, particularly when size differences among streams are great. Differences in drainage area affect the time of concentration, or the period needed for water to drain from upland areas. Distance along a stream channel also affects runoff timing, as a flood peak needs some time to move down the channel.

Examining monthly instead of daily flow reduces the effects of runoff timing in correlation of sites. Log-transformed monthly mean flow was also significantly ($p < 0.01$) correlated between all pairings of the three streams in the Ballard Fork Watershed. As with the daily mean flows, the correlation was strongest between Spring Branch and Ballard Fork ($R^2 = 0.904$), second strongest between the Unnamed Tributary and Ballard Fork ($R^2 = 0.548$), and weakest between the Unnamed Tributary and Spring Branch ($R^2 = 0.312$) (fig. 7). Flow records for Spring Branch for February 2000 and April and May 2001 were excluded from this analysis because more than half the total flow during these months was estimated (Ward and others, 2001, 2002). The flow record for October 2001 for Spring Branch was also excluded because the average flow for the month was zero, which could not be log-transformed.

Most of these correlations were surprisingly weak. For example, the correlation between log-transformed flow at Coal River at Tornado (862 mi^2) and a tributary, Big Coal River at Ashford (391 mi^2), was significant and strong for both daily ($p < 0.001$; $R^2 = 0.968$) and monthly ($p < 0.001$; $R^2 = 0.985$) mean flow during the study period (data not shown). The correlations between log-transformed flow at Coal River at Tornado and Clear Fork at Whitesville (62.8 mi^2), a Big Coal River tributary that drains less than 10 percent of the area that the Coal River drains at Tornado, were also stronger than five of the six correlations among pairs of sites in the Ballard Fork Watershed ($p < 0.001$, $R^2 = 0.823$ for daily mean flow; $p < 0.001$, $R^2 = 0.866$ for monthly mean flow) (data not shown).

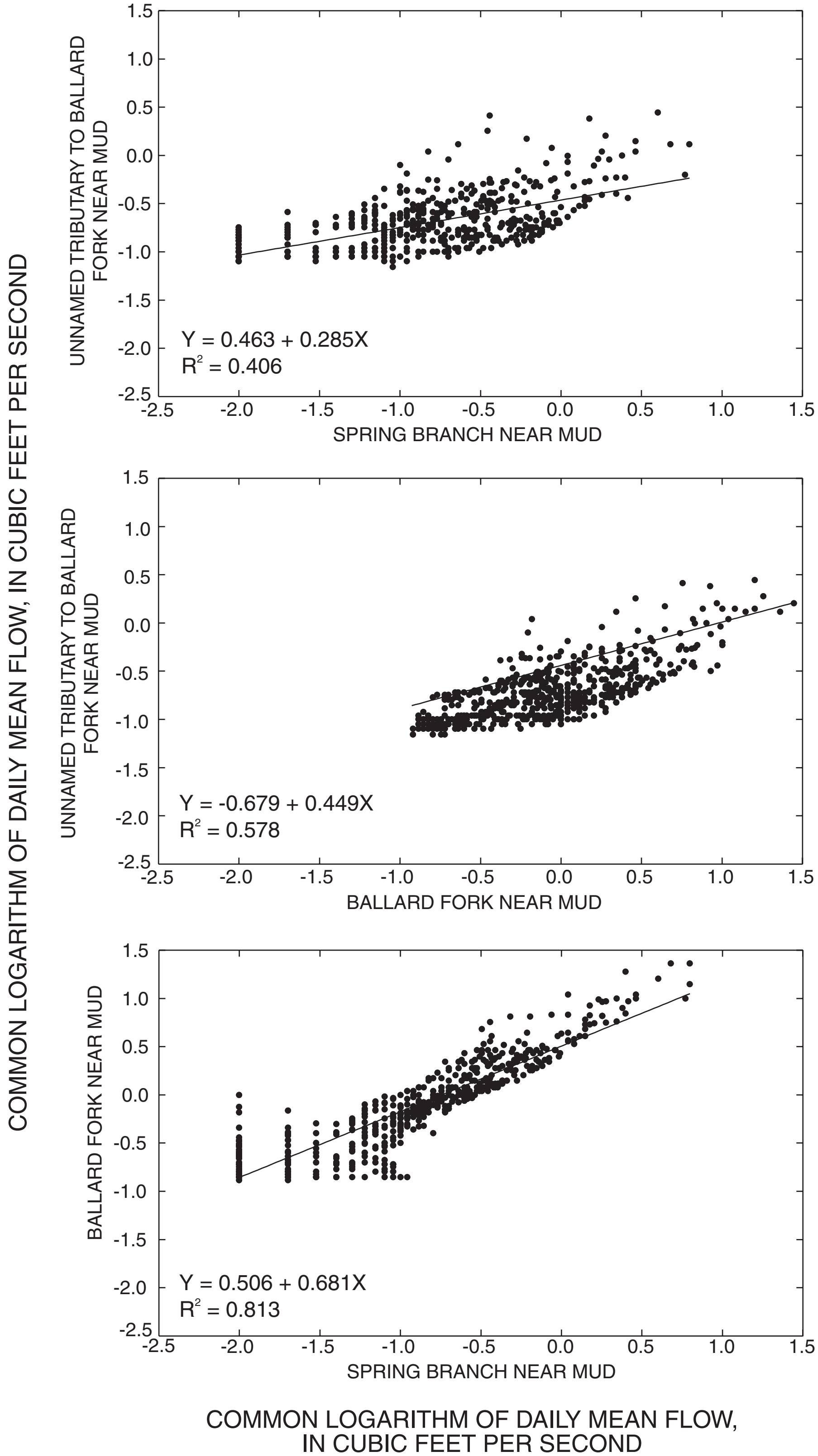


Figure 6. Relation of daily mean flow among three streams in the Ballard Fork Watershed, West Virginia, 1999–2001.

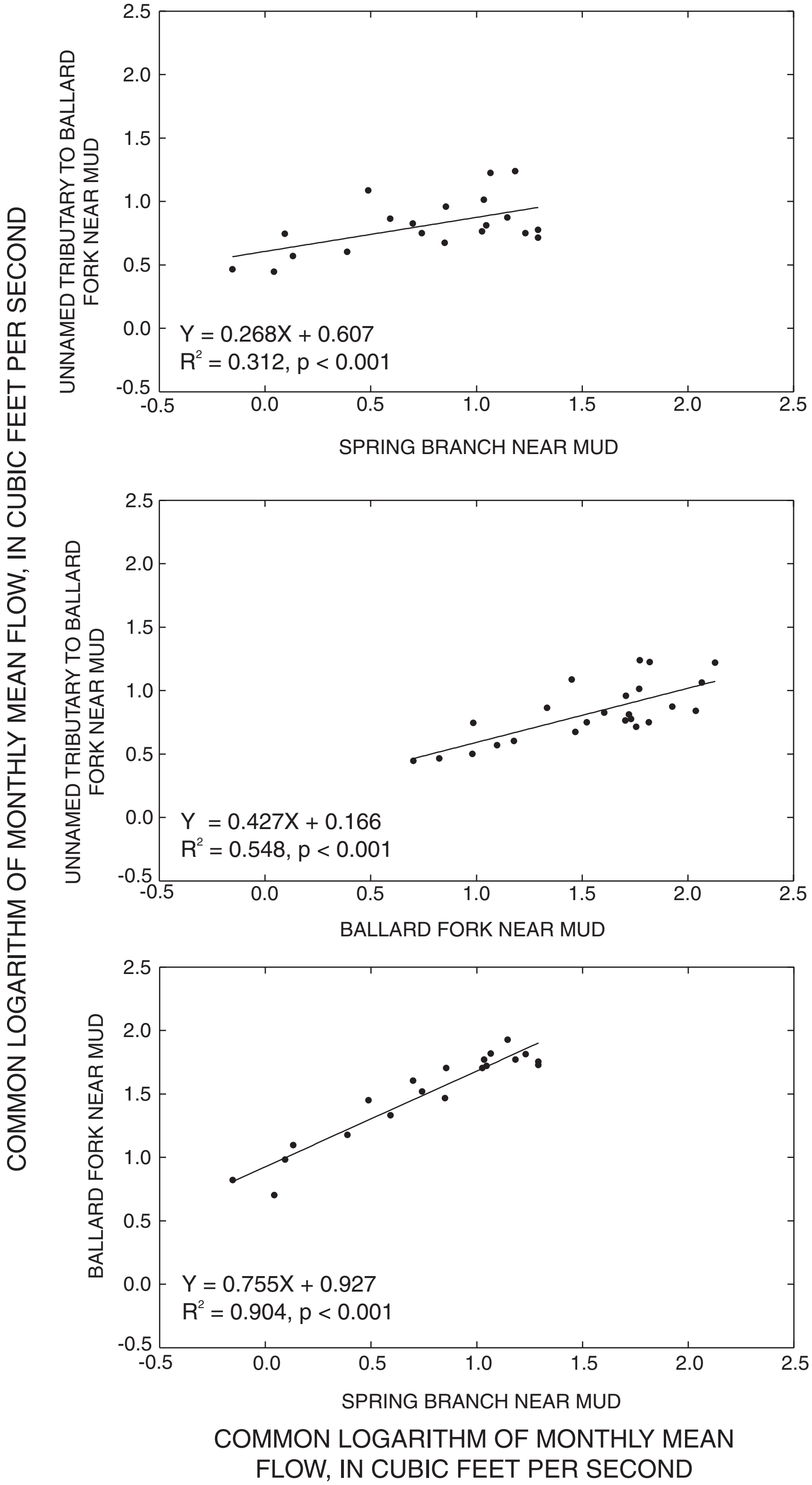


Figure 7. Relation of monthly mean flow among three streams in the Ballard Fork Watershed, West Virginia, 1999–2001.

Flow data for the streams in the Ballard Fork Watershed were compared to data for the study period from the candidate index sites, which included seven active stream-gaging stations with 20 or more years of continuous flow records on unregulated streams in southern West Virginia (table 3). Daily and monthly mean flow data (log-transformed) for each of the three streams in the Ballard Fork Watershed were significantly correlated with flow data for each of the candidate index sites ($p < 0.01$). Flow data from Spring Branch and Ballard Fork were correlated more strongly to flow data for East Fork Twelvepole Creek near Dunlow than to any of the other sites (table 3). Flow data for the Unnamed Tributary were correlated more strongly to flow data for Coal River at Tornado than to flow data for any of the other sites (table 3). East Fork Twelvepole Creek was closer geographically to the Ballard Fork Watershed than was any of the other sites, and also drained the smallest area, even though it drained more than 10 times the area of Ballard Fork. Because using two separate index sites was judged to be too complex and confusing, East Fork Twelvepole Creek was selected as the index site for the entire study on the basis of its basin characteristics and strong correlation with Spring Branch, the unmined site.

Monthly total precipitation data (1966–2001) for Madison and Dunlow, 29 miles apart, are significantly ($p < 0.001$) but weakly ($R^2 = 0.52$) correlated (fig. 8). Correlation between log-transformed monthly total precipitation data for the Ballard Fork Watershed and Dunlow during the study period (1999-2001) was stronger ($p < 0.001$, $R^2 = 0.846$; fig. 9) than the correlation for the long term (1966–2001) record at Madison and Dunlow.

Evapotranspiration

A substantial amount of rain that falls in a watershed evaporates or is transpired by plants, particularly trees. Evaporation can be measured, but transpiration is often a more important component of overall evapotranspiration, and it cannot be measured from mature trees. Evapotranspiration is estimated by subtracting total flow, loss to any regional aquifer system, and change in soil moisture and aquifer storage from total precipitation over a watershed area. For the estimate to be reasonable, storage in aquifers and soils must be the same at the beginning and end of the period under consideration. The amount of water stored in soils is usually most consistent from year to year during the annual low-flow period. Because of this, evapotranspiration is usually estimated on an annual basis, with a beginning and ending date selected during the lowest flow period of the year; the water year runs from October 1 through the following September 30 for ease in estimating evapotranspiration (Black, 1996).

Table 3. Correlation coefficients for linear regressions of log-transformed daily and monthly mean flow for six candidate index stream-gaging stations and three stream-gaging stations in the Ballard Fork Watershed, West Virginia, November 1999–November 2001

[Flow values of zero were deleted before analysis. mi^2, square miles]

Stream gage	Station No.	Drainage area (mi^2)	Period of record	Correlation coefficients: Unnamed Tributary to Ballard Fork near Mud		Spring Branch to Ballard Fork		Ballard Fork near Mud	
				Daily	Monthly	Daily	Monthly	Daily	Monthly
Big Coal River at Ashford	03198500	391	1908–16, 1930–2001	0.490	0.516	0.516	0.739	0.721	0.688
Coal River at Tornado	03200500	862	1908–11, 1911–12, 1928–31, 1961–2001	.518	.531	.537	.797	.742	.743
Guyandotte River near Baileysville	03202400	306	1968–2001	.435	.493	.422	.540	.590	.575
Clear Fork at Clear Fork	03202750	126	1974–2001	.457	.519	.517	.745	.720	.720
East Fork Twelvepole Creek near Dunlow	03206600	38.5	1964–2001	.346	.325	.652	.895	.758	.778
Tug Fork at Williamson	03213700	936	1967–2001	.433	.461	.467	.687	.634	.696

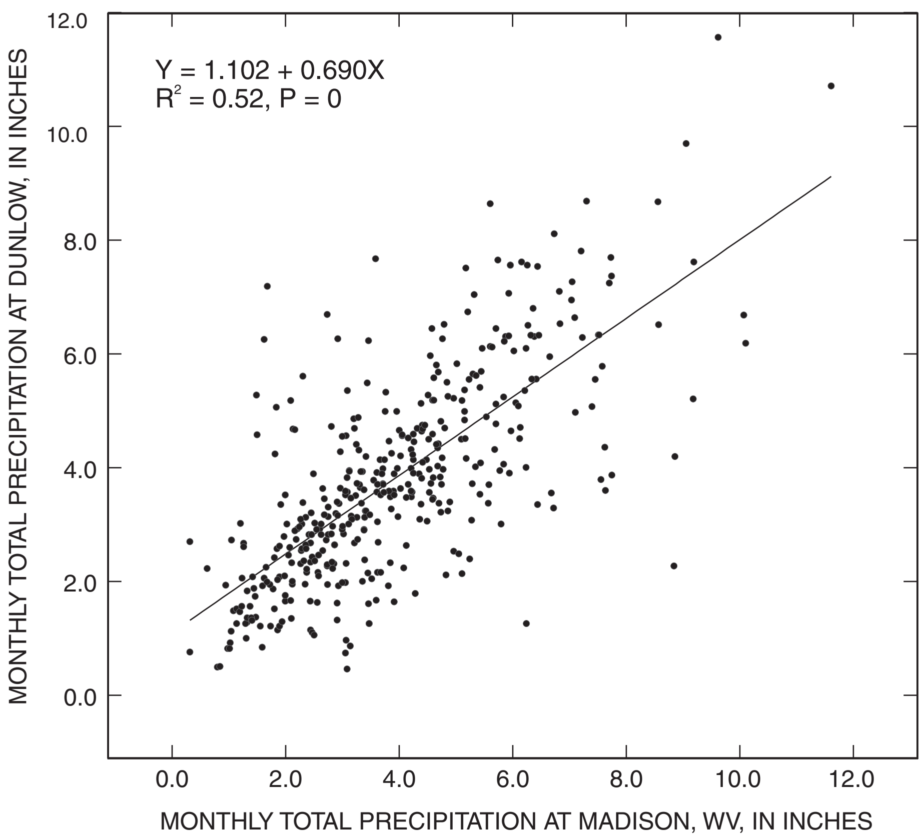


Figure 8. Relation between monthly total precipitation at Madison and Dunlow, West Virginia, 1966–2001.

Few studies appear to have been done of the mechanisms of evapotranspiration on reclaimed surface mines in the Appalachian Mountains. A great deal is known about evapotranspiration in forests (generally the most important pre-mining land use in the region), and most studies on forest cutting or manipulation have shown that loss of trees decreases evapotranspiration, even if the studies disagree or are ambiguous as to the relative importance of different mechanisms of evapotranspiration (Black, 1996). In order of the passage of water through the system, the principal mechanisms of evapotranspiration in forests are: evaporation of water intercepted by leaves in the canopy and on the forest floor, evaporation of water from soil, and transpiration of water by trees. Of these, only evaporation from soils is likely to be increased by surface mining.

In a forest ecosystem, rain first passes through the forest canopy and soils and satisfies any moisture deficits before it can run off to a stream or recharge an aquifer. About 10 percent of rain is intercepted in deciduous forests in the United States when leaves are open (Helvey and Patric, 1965; Helvey and Patric, 1988). Water intercepted by the forest canopy evaporates while rain continues to fall as long as relative humidity in the canopy is less than 100 percent. Plants transpire water in order to photosynthesize, and use transpiration as a pump to pull dissolved soil nutrients into leaves (Brewer, 1988). Transpiration rates increase as relative humidity increases, because guard cells in leaves open during humid periods when water loss and wilting decrease. A difference in relative humidity between the canopy and soil is the mechanism that powers transpiration, however, so that when relative humidity is near or at 100 percent, transpiration decreases or temporarily stops. Evapotranspiration rates are generally at their annual maximum for deciduous trees during the first months after leaves fully open. In southern West Virginia, leaves open during late April, and transpiration is greatest during May, June, and July. After July, some tree species begin to lose leaves, which decreases interception, and transpiration rates decrease in most species.

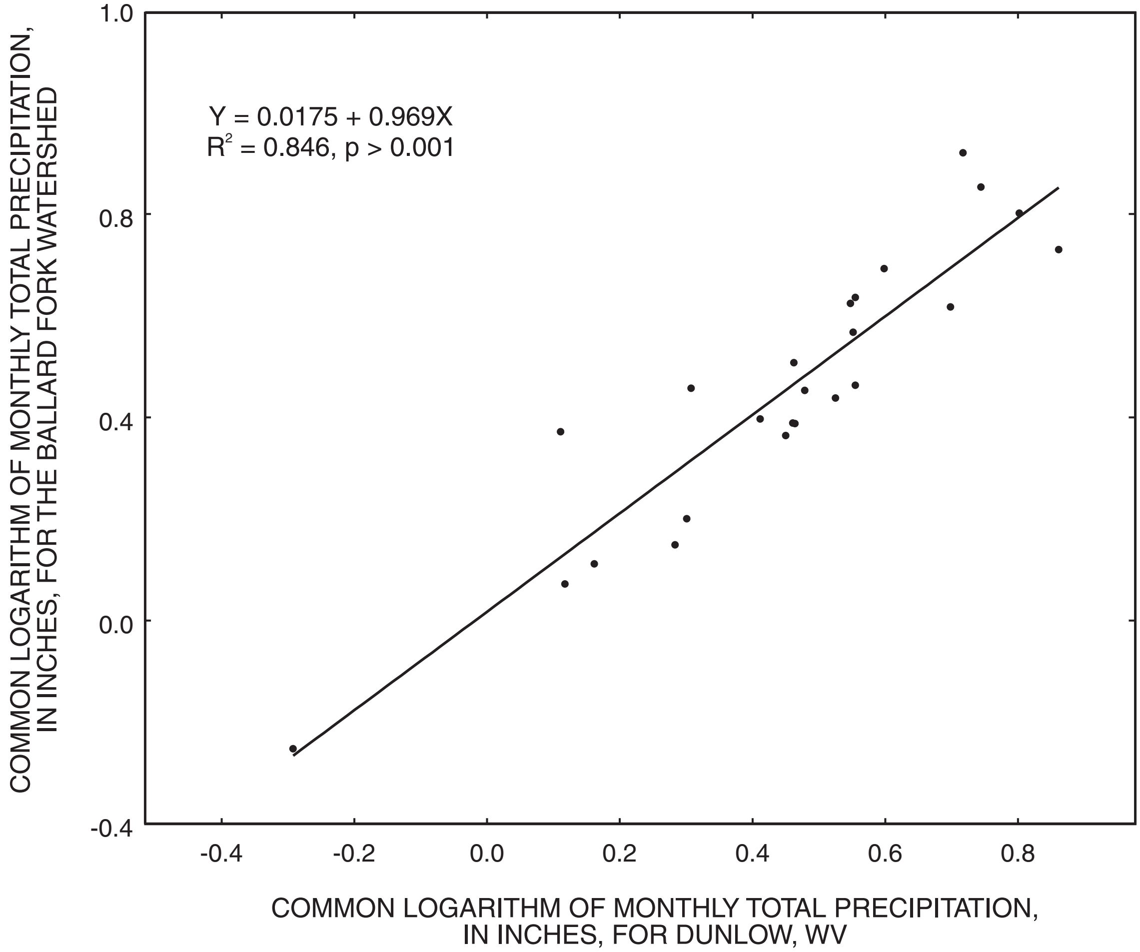


Figure 9. Relation between monthly total precipitation in the Ballard Fork Watershed and at Dunlow, West Virginia, 1999–2001.

Leaf litter, at the interface between vegetation and soil, can intercept a substantial amount of rain, but the amount depends on antecedent moisture conditions. Helvey (1964) reports that leaf litter becomes fully saturated with water only after about 1 inch of throughfall, but estimates that leaf litter in a study site in a southern Appalachian hardwood forest at the Coweeta, NC, Long-Term Ecological Research Station, intercepted 2 to 4 in. of rain annually, or about 2 to 5 percent of annual precipitation. Interception by leaf litter is greatest in the autumn, immediately after leaves fall, and decreases as dead leaves are consumed by animals, fungi, and bacteria or are mechanically broken down. Leaf litter also reduces evaporation from forest soils by shading them. Soil-moisture evaporation is greatly reduced in a forest not only because of leaf litter, but because wind speeds are greatly reduced (Brewer, 1988). Leaf litter and wind-speed reduction decrease evaporation from forest soils year-round, so that evapotranspiration may be less from a deciduous forest than an open area, such as a surface mine, during part of the year.

Estimated Evapotranspiration

There is no regional aquifer system in southern West Virginia. Valley fills in the study area had been in place for several years prior to the study and therefore ground-water storage in them was probably at equilibrium with precipitation, so that the study area met assumptions for estimating evapotranspiration. One exception was that in this study, stream-gaging stations were not installed by October 1, 1999, so that estimating evapotranspiration using a standard water year was not possible. When stream-gaging stations were installed and operating, on November 6, 1999, streams in the Ballard Fork Watershed were above base flow because of rains on November 2;

therefore, analyzing flow statistics for a study year beginning November 6 would have introduced substantial error into evapotranspiration estimates. For this study, using a study year beginning November 15 and ending November 14 best met the storage assumptions for estimating evapotranspiration.

Evapotranspiration, as a percentage of total rainfall, decreased substantially from the first to the second, drier, year in the Unnamed Tributary Watershed, from 61 percent to 49 percent; but was about the same during both years in the Spring Branch (77 and 76 percent) and Ballard Fork (73 and 76 percent) Watersheds. Evapotranspiration from the Unnamed Tributary Watershed was less during both years of the study than from either the Spring Branch or Ballard Fork Watersheds.

Evapotranspiration as a percentage of total rainfall from the East Fork of Twelvepole Creek Watershed was greater during the study period (78 percent both years) than the 1965–2001 average (60 percent). Seasonality of precipitation during the study period explains the high evapotranspiration rate. As discussed previously, precipitation in the first year of the study was well below normal for winter and spring but above normal for summer, and greatly below normal in the second year of the study except for a storm in May and a storm in July.

Differences in total unit flow among the three streams in the Ballard Fork Watershed probably reflect the differences in evapotranspiration among the three watersheds. Although quantitative information on leaf area and litter thickness is not available for the study area, the qualitative differences in these characteristics are obvious from inspection of the study area; interception of rainwater by foliage and litter is undoubtedly much greater in the forested areas than mined areas. Transpiration by plants is also undoubtedly much greater in forested areas than in mined areas because of obvious differences in plant biomass and species composition. Before water can be transpired, however, it must be stored in soil. Field reconnaissance showed that the mined parts of the watershed were covered with thin, compacted soil, therefore, soil storage that would allow transpiration is probably decreased in the mined areas.

Seasonal Flow-Evapotranspiration Partitioning

Changes in monthly mean unit flow per monthly total precipitation (referred to from here forward as "monthly flow per precipitation") represent how the relation between runoff and evapotranspiration changes seasonally. Monthly flow per precipitation from Spring Branch only exceeded that from the Unnamed Tributary during late winter and early spring, in February–April 2000, and February–March 2001, the season when evaporation from soils is most likely to be the most important mechanism of evapotransporation (fig. 10). Monthly flow per precipitation from the Ballard Fork Watershed was usually closer in magnitude to that from the Spring Branch Watershed than to that from the Unnamed Tributary Watershed, except during February and March during both years, when unit monthly mean flow from Spring Branch exceeded unit monthly mean flow from the Unnamed Tributary, and during June 2000.

Log-transformed monthly flow per precipitation was significantly related to log-transformed unit monthly mean flow for Spring Branch ($R^2 = 0.698$, $p < 0.001$) and Ballard Fork ($R^2 = 0.550$, $p < 0.001$), but not for the Unnamed Tributary ($R^2 = 0.042$, $p = 0.335$) (fig. 11). For the East Fork of Twelvepole Creek Watershed, long-term log-transformed monthly flow per precipitation was significantly correlated with log-transformed monthly flow ($R^2 = 0.872$, $p < 0.001$) (fig. 12). Comparing monthly unit flow to monthly flow per precipitation shows that monthly flow per precipitation was high in the Unnamed Tributary in some months when flow was low (fig. 11).

The relation between log-transformed monthly precipitation and flow was significant ($p < 0.01$) for all three streams in the Ballard Fork Watershed (fig. 13), and was strongest for the Unnamed Tributary ($R^2 = 0.493$) and Ballard Fork ($R^2 = 0.531$). The relation was weaker for Spring Branch ($R^2 = 0.354$). The relation at Spring Branch is probably weaker because seasonal changes in evapotranspiration are more important in the Spring Branch Watershed than in the the Unnamed Tributary Watershed and other mined parts of the study area.

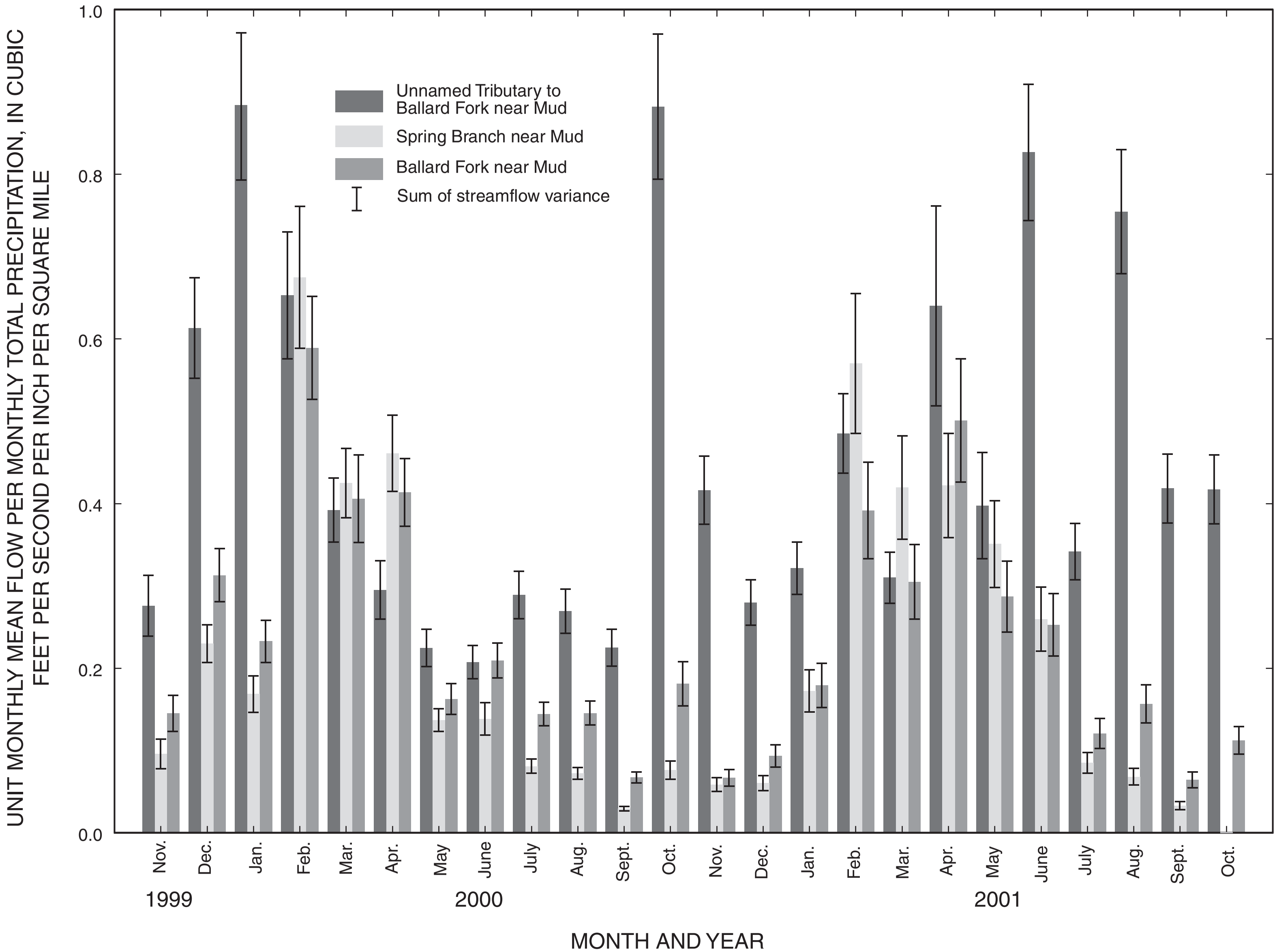


Figure 10. Unit monthly mean flow per monthly total precipitation for three sites in the Ballard Fork Watershed, West Virginia, 1999–2001. Error bars represent the sum of daily mean streamflow variance determined from estimates of data quality made by Ward and others (2001, 2002). Spring Branch had an average flow of zero during October 2001.

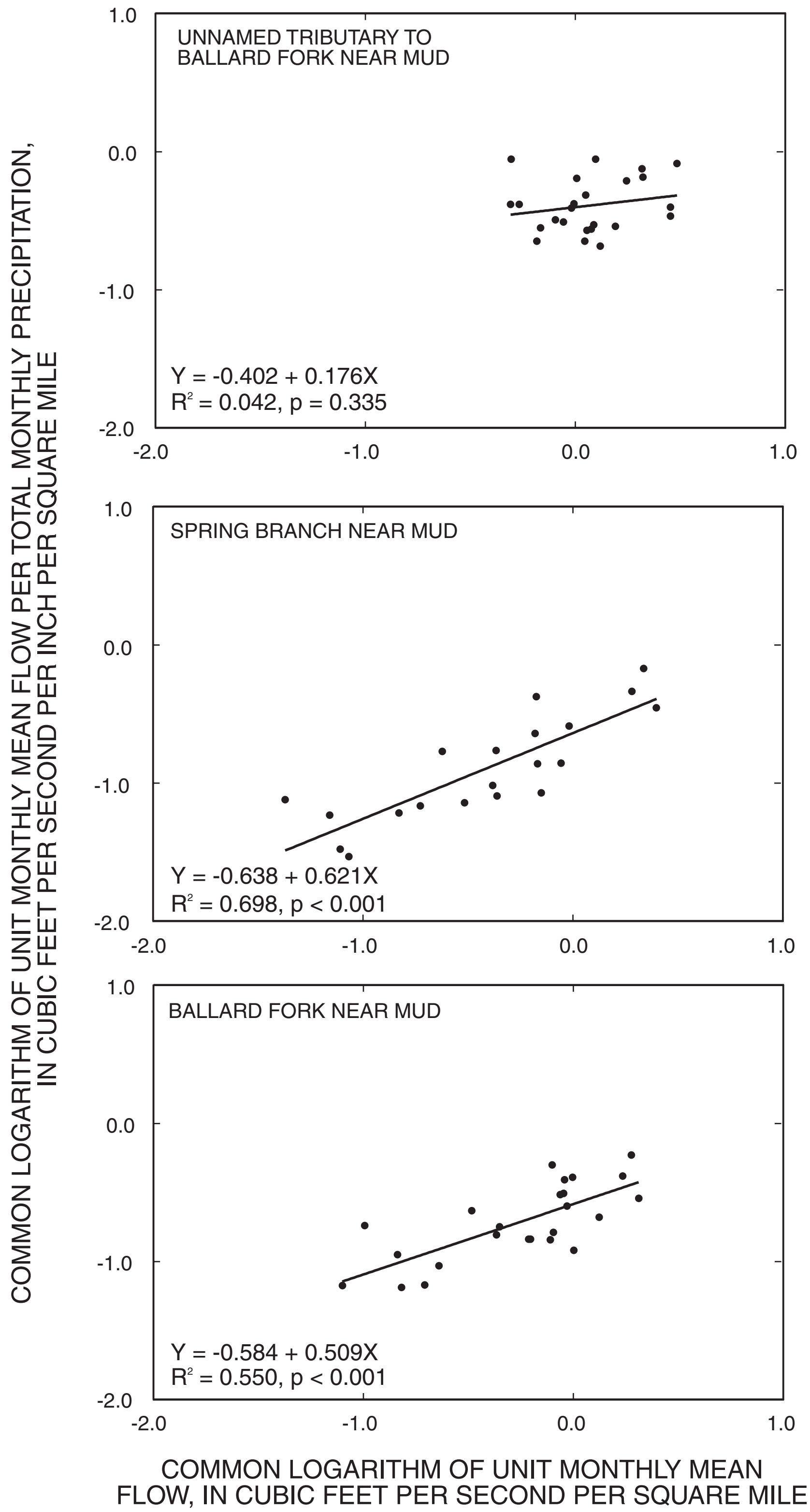


Figure 11. Relation between monthly mean flow and monthly mean flow per monthly total precipitation for three streams in the Ballard Fork Watershed, West Virginia, 1999–2001.

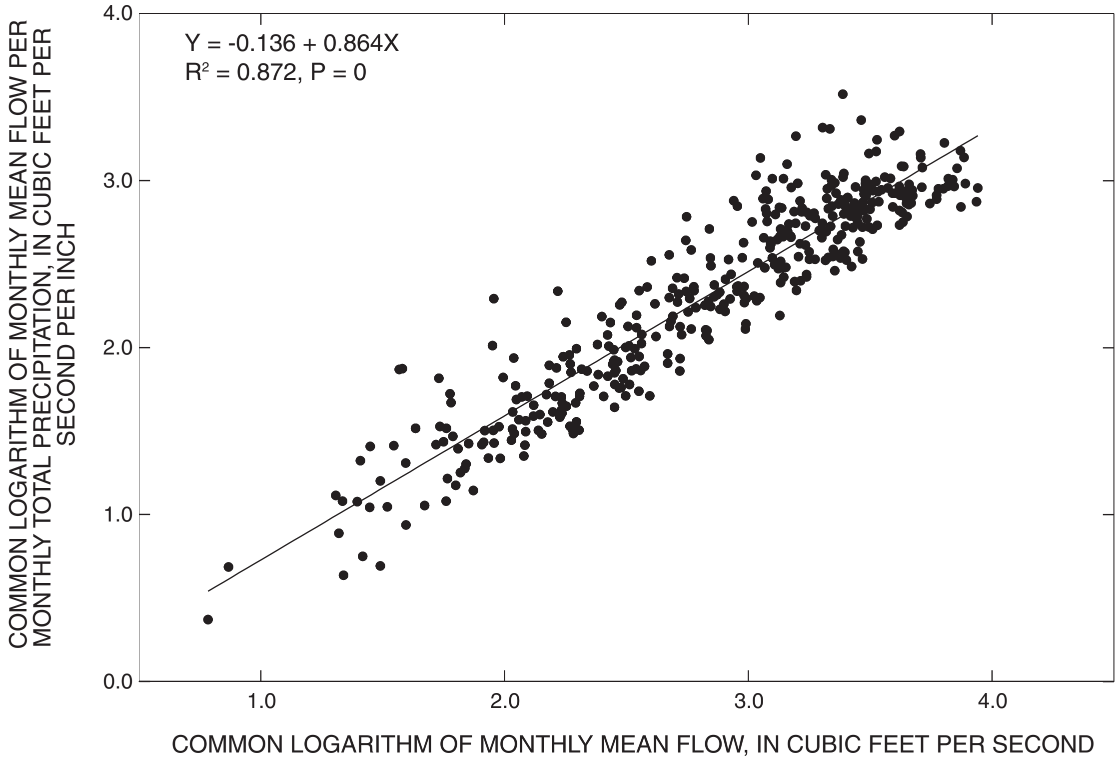


Figure 12. Relation between monthly mean flow and monthly mean flow per monthly total precipitation for East Fork Twelvepole Creek near Dunlow, West Virginia, 1965–2001.

Monthly flow per precipitation from the Unnamed Tributary Watershed greatly exceeded that from the Spring Branch Watershed during several months, and monthly flow per precipitation from the Spring Branch Watershed never greatly exceeded that from the Unnamed Tributary (fig. 10). Five of the months when monthly flow per precipitation from the Unnamed Tributary Watershed greatly exceeded that from the Spring Branch Watershed were summer or fall months, suggesting an evapotranspiration difference. However, a limitation of analyzing the partitioning between evapotranspiration and flow on a monthly basis is that frequently, precipitation that is received near the end of a month does not leave the watershed as flow until the following month (Black, 1996). In fact, four of the months when monthly flow per precipitation from the Unnamed Tributary Watershed greatly exceeded that from Spring Branch followed months when the average precipitation for the study area during the last week of the month was 0.75 in. or more (table 4). Recessions on the Unnamed Tributary from most storms took longer and contained more unit flow than on Spring Branch (Messinger, 2003). Usually, flow on the Unnamed Tributary was still higher than pre-storm base flows 4 or 5 days after a storm, in contrast to Spring Branch, where storm flows returned to near pre-storm flows within 12 to 24 hours of the end of rainfall (Messinger, 2003). During some months when monthly flow per precipitation from the Unnamed Tributary greatly exceeded that from Spring Branch, much of the extra water might have been delayed flow from the previous month’s rain.

Flow Duration

Unit flow-duration curves for the index site, East Fork Twelvepole Creek near Dunlow, were computed for the period November through October for the entire length of record (1965–2001) and for the study period (2000–2001). The flow duration curve computed for East Fork Twelvepole Creek for the period of record (1965–2001) generally plots above the flow duration curve computed for the study period (fig. 14). The relative postitions of the two curves for the index site indicate that the flows for the study period were below average.

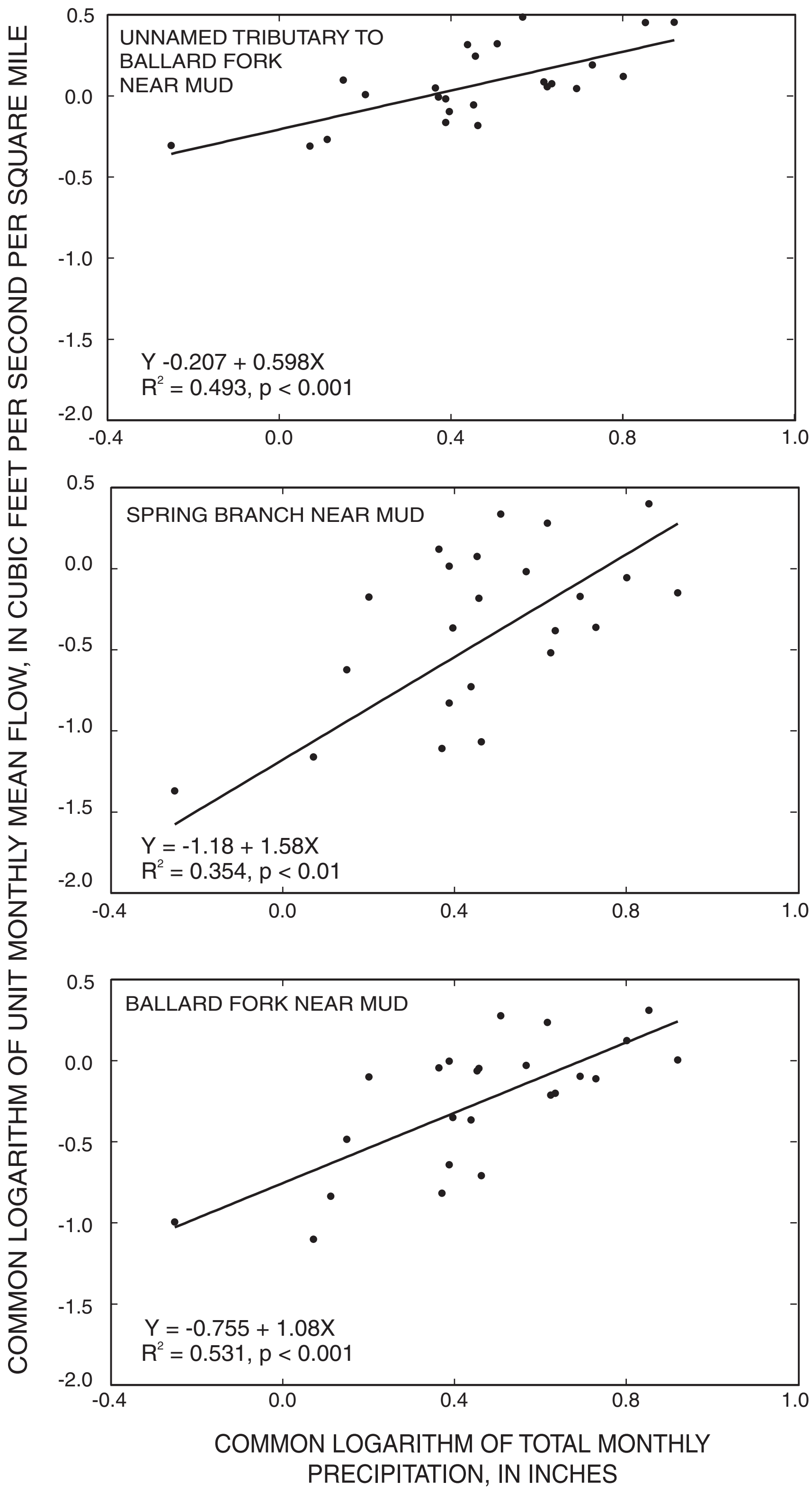


Figure 13. Relation between monthly mean flow and monthly total precipitation for three streams in the Ballard Fork Watershed, West Virginia, 1999–2001.

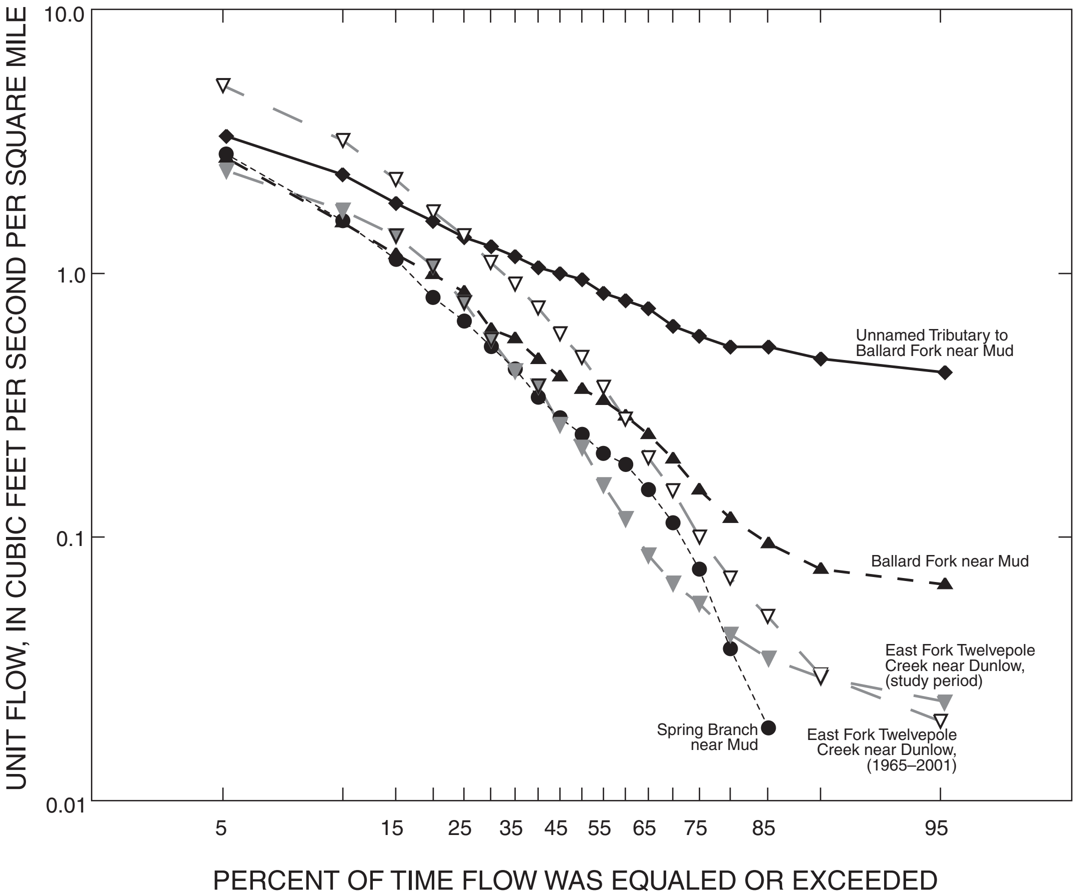


Figure 14. Flow duration of three streams in the Ballard Fork Watershed and of East Fork Twelvepole Creek near Dunlow, West Virginia.

The low part of the unit flow-duration curve for the Unnamed Tributary plots above the flow-duration curve for Ballard Fork, and both curves plot above the curve for Spring Branch. The low parts of both unit flow-duration curves for East Fork Twelvepole Creek near Dunlow are similar to the curve for Spring Branch.

This relationship among flow-duration curves at low flow indicates that the lowest unit flow was in Spring Branch, which dries up; the greatest unit flow was in the Unnamed Tributary and intermediate unit flow was in Ballard Fork (fig. 14). The flow-duration curves indicate that unit low flows were greater in the Unnamed Tributary, probably because of (1) less evapotranspiration on the mined areas as compared to forested areas and (2) drainage of water stored in the valley fill. Unit flows from the Ballard Fork Watershed also are greater than from the Spring Branch Watershed. The unit 90-percent-duration flow in other small streams that emerge from the toes of valley fills is about six to seven times greater than in nearby streams that drain unmined watersheds (Wiley and others, 2001).

The high parts of the unit-flow duration curves for East Fork Twelvepole Creek during the study period, Spring Branch, and Ballard Fork are approximately together, slightly below the curve for the Unnamed Tributary (fig. 14). These relative positions indicate that above-median flows were increased by mining activities. The duration curves were not compared above 5 percent or below 95 percent because the short period of record makes the extremes of the curve unreliable. For example, the stage sensor for the Spring Branch stream-gaging station malfunctioned on several days in May 2001, when flow at Ballard Fork was highest during the study period.

Flow Variability

One index of flow variability is the standard deviation of the logarithms of flow values from the flow-duration curve at 5-percent intervals, from 5 to 95 percent. Larger index values represent greater variability. Friel and others (1989) geographically categorized this flow-variability index for West Virginia on the basis of long-term flow records and surficial geology. Statewide values ranged from 0.32 to 0.99; the Ballard Fork Watershed is in an area with a value of 0.85. Flow-variability index values for the 2-year period of record for the Unnamed Tributary (0.24) and Ballard Fork (0.46) were substantially less than values at nearby stream-gaging stations, and the index value for the Unnamed Tributary was smaller than any long-term value in West Virginia. The flow-variability indexes calculated for East Fork Twelvepole Creek near Dunlow for the study period (0.62) and for the period of record (0.70) were both less than values for nearby stream-gaging stations. The flow-variability index could not be calculated for Spring Branch, because Spring Branch recorded periods of no flow, so the Unnamed Tributary and Ballard Fork could best be contrasted with the index value for their area (0.85). The low values of the flow-variability index for the mined watersheds reflect increased low flows downstream from mined areas.

High Flows[1]

During storms when rainfall intensity exceeded about 1 inch per hour, peak unit runoff from the Unnamed Tributary (the mined watershed) exceeded peak unit runoff from Spring Branch (the unmined watershed) (Messinger, 2003). During most storms—those with intensity less than about 1 inch per hour—peak unit flows were greater from the unmined watershed than the mined watershed. One storm that produced less than an inch of rain before flow from the previous storm had receded caused peak unit flow from the Unnamed Tributary to exceed peak unit flow from Spring Branch. Peak unit flow was usually similar in Spring Branch and in Ballard Fork. Peak unit flows are expected to decrease with increasing watershed size in homogeneous watersheds.

After all storms in which maximum rainfall intensity exceeded about 0.25 in. per hour, the storm hydrograph from the Unnamed Tributary showed a double peak, as a sharp initial rise was followed by a decrease in flow and then a delayed secondary peak of water that had apparently flowed through the valley fill (Messinger, 2003). The initial peak appears to be caused by Hortonian (excess overland) flow from areas with compacted soil; this flow was possibly conveyed through drainage structures on the mine. Ballard Fork and the unmined watershed had hydrographs with single peaks, typical of elsewhere in West Virginia. Runoff patterns from the mined watershed are influenced by the compaction of soils on the mine, the apparent low maximum infiltration rate into the valley fill compared to the forested watershed, storage of water in the valley fill, and the absence of interception from trees and leaf litter.

During all storms with 1-hour rainfall greater than 0.75 in. or 24-hour rainfall greater than 1.75 in. and with a complete record at all three stream-gaging stations, the Unnamed Tributary yielded the most total unit flow (Messinger, 2003). In three selected major storms, total unit flow from the Unnamed Tributary was greatest during recessions, and its total unit flow was greatest among the streams during all three recessions.

No storms during this study produced 1-hour or 24-hour rainfall in excess of the rainfall with the 5-year return period, and flow during this study never exceeded a magnitude equivalent to the flow with the 1.5-year return period; relative peak unit flow among the three streams in this study could be different in larger storms (Messinger, 2003). Rainfall-runoff relations on altered landscapes are site-specific, and aspects of mining and reclamation practice that affect storm response may vary among mines.

[1]This section is based on another report, which discusses storm response of the streams in the Ballard Fork Watershed in more detail (Messinger, 2003).

SUMMARY AND CONCLUSIONS

Unit daily mean flow was higher from the Unnamed Tributary, which drains a predominantly mined watershed, than from Spring Branch, which drains an unmined, forested watershed, at all flows between 5- and 95-percent duration. The proportional difference was greatest at lower flows. Unit daily mean flows from Ballard Fork, which drains a watershed including both of the other streams and is about 30 percent mined, were about the same as those from Spring Branch at higher flows (greater than about 15-percent duration), and were intermediate between the Unnamed Tributary and Spring Branch the rest of the time. Spring Branch dried up during both years of the study, and its mean flow in October 2001 was zero; the Unnamed Tributary had flow throughout the study period. Some of the flow from the mined area is delayed. Storage of water in or under the valley fill is the most likely mechanism.

Total unit flow for the 2-year study period on the Unnamed Tributary (11,700 $ft^3/s/mi^2$) was almost twice that on Spring Branch (6,260 $ft^3/s/mi^2$), and about 1.75 times that on Ballard Fork (6,690 $ft^3/s/mi^2$). Storage of water in the valley fills does not seem likely to cause this difference, because all the flow in the Ballard Fork Watershed originated as precipitation, and precipitation was the same on mined and unmined areas. Reduced evapotranspiration in the mined areas probably accounts for the difference in total flow. Evapotranspiration from mined areas was probably less than that from forested areas because most mechanisms of evapotranspiration, such as interception and transpiration, are functions of plants and plant biomass and species composition are much different in mined areas than in unmined areas. Differences in interception by foliage and litter are caused by the differences in plant biomass and species composition. Differences in transpiration are related to the differences in vegetation and also to different storage properties in mined areas, as soil is thinner and more compacted in mined areas than in unmined areas. The difference in total flow and low flow between the mined and unmined areas will probably change as soil, plant biomass, and plant-species composition change on the reclaimed mines.

The daily hydrograph shows that summer and autumn flows were higher in the Unnamed Tributary than Ballard Fork, and higher in Ballard Fork than in Spring Branch. Spring Branch was dry during much of October and November 2000, and its monthly mean flow for October 2001 was zero. Ballard Fork and the Unnamed Tributary had flow throughout the study period. Log-transformed daily mean flow was significantly ($p < 0.01$) correlated among the three streams in the Ballard Fork Watershed. This correlation was strongest between Spring Branch and Ballard Fork ($R^2 = 0.813$), weakest between Spring Branch and the Unnamed Tributary ($R^2 = 0.406$), and intermediate between Ballard Fork and the Unnamed Tributary ($R^2 = 0.578$).

The highest monthly flow in the study period in Ballard Fork was during May 2001, because of a series of thunderstorms that produced 6.22 in. of rain in 8 days (May 15 to May 22). The maximum monthly total flow on the Unnamed Tributary was in June 2001, although flows were similar from May through July 2001, the usual period of maximum evapotranspiration in forested watersheds.

Flow-duration curves show the lowest unit flows from Spring Branch, the highest unit flows from the Unnamed Tributary, and intermediate unit flows from Ballard Fork. Unit flow from the Unnamed Tributary Watershed was the highest of the three streams at all flows analyzed, between 5- and 95-percent flow duration, but the proportional difference was greatest for low flows. Low flows in the Unnamed Tributary were probably increased because of decreased evapotranspiration from the mine as compared to the forest and delayed drainage of water stored in the valley fill. Unit flows from Ballard Fork and Spring Branch were about the same at higher flows, but unit flow from Ballard Fork was much higher than that from Spring Branch at low flow.

Reduced evapotranspiration in mined areas probably accounts for the marked differences in total and low unit flow between the Unnamed Tributary and Spring Branch Watersheds. Evapotranspiration, as a percentage of total rainfall, decreased from the first to the second year from the Unnamed Tributary Watershed (from 61 percent to 49 percent) but changed little from the Spring Branch (from 77 to 76 percent) and Ballard Fork (73 to 76 percent) Watersheds. Evapotranspiration from the East Fork of Twelvepole Creek Watershed was much higher during the study period (76 percent the first year, and 78 percent the second year) than the 1965–2001 average (60 percent). Rates of evapotranspiration from most mechanisms appear to be lower on reclaimed surface mines than in forests, because most mechanisms evolved in plants to use or conserve water. Plant biomass in the mined areas is much less than in forested areas.

Unit flow per unit precipitation from Spring Branch only exceeded that from the Unnamed Tributary during February to April 2000 and February to March 2001, periods before leaves emerged, but even then, exceeded it by less than measurement error. Unit flow per unit precipitation from the Unnamed Tributary Watershed exceeded that from the Spring Branch Watershed during summer and fall months.

Long-term conditions were assessed by comparison with nearby sites with long periods of record. Hydrologic conditions observed during the study period were drier than long-term averages at three nearby long-term sites, the USGS stream-gaging station East Fork Twelvepole Creek near Dunlow, West Virginia, and two NOAA rain gages at Madison and Dunlow. Total precipitation in 2000 at both Madison and Dunlow (46.2 and 47.4 in., respectively) was close to long-term averages (47.8 and 45.7 in., respectively, 1971–2000), but was substantially less in 2001 (40.2 and 35.0 in., respectively). Flow at East Fork Twelvepole Creek was well below the long-term average during both years. The disparity between normal precipitation and low flow in 2000 resulted from a large proportion of that year's precipitation being received during the summer, when much of it was evaporated or transpired. Precipitation at Madison was 4.71 in. below average from November 1999 through March 2000, the season of maximum recharge and runoff, and exceeded the long-term average during only 3 months, April (by 0.24 in.), June (by 1.76 in.), and July (by 0.20 in.), in the period of maximum evapotranspiration.

This study did not address mechanisms of water movement through valley fills, or details of valley-fill structure. Water is likely to move differently through valley fills that are different structurally than those in the Ballard Fork Watershed, and streams draining them are likely to have different flow characteristics than the streams in this study. Determining mechanisms of water movement across the mine and through the fill in relation to vegetation, soil characteristics, and fill structure would provide valuable information for mine regulators and operators, but was outside the scope of this study. Measuring the same flow characteristics as in this study in another set of watersheds would provide valuable information on the transferability of this study's results; without such reproduction, the results of this study should not be considered to apply to other watersheds with different geology, landforms, and mining practices and permit details. Continuing to operate the stream-gaging stations and precipitation gages from this study could provide valuable information on trends and on changes in flow characteristics in the mined parts of the watershed, as vegetation and soils continue to develop following reclamation.

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Table 4

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001

[--, no data]

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
November 1999					
1	0.02	--	0.02	--	0.02
2	.87	--	1.17	--	1.02
3	.18	--	.00	--	.09
4	.00	--	.00	--	.00
5	.00	--	.00	--	.00
6	.00	--	.00	0.00	.00
7	.00	--	.00	.00	.00
8	.00	--	.00	.00	.00
9	.00	--	.00	.00	.00
10	.00	--	.00	.00	.00
11	.00	0.00	.00	.00	.00
12	.00	.00	.00	.00	.00
13	.00	.00	.00	.00	.00
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.00	.00	.00	.00	.00
17	.00	.00	.00	.00	.00
18	.00	.00	.00	.00	.00
19	.00	.00	.00	.00	.00
20	.00	.00	.00	.00	.00
21	.00	.00	.00	.00	.00
22	.00	.00	.00	.00	.00
23	.00	.00	.00	.00	.00
24	.52	.39	.59	.43	.48
25	1.38	2.16	2.17	2.14	1.96
26	1.17	.67	.47	.67	.75
27	.00	.00	.00	.00	.00
28	.00	.00	.00	.00	.00
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
December 1999					
1	0.00	0.00	0.00	0.00	0.00
2	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00
4	.02	.04	.03	.04	.03
5	.13	.16	.14	.16	.15

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
December 1999—*Continued*					
6	0.02	0.03	0.03	0.02	0.03
7	.00	.00	.00	.02	.01
8	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00
10	.57	.60	.60	.62	.60
11	.00	.00	.00	.00	.00
12	.00	.00	.00	.00	.00
13	.79	.63	1.13	.64	.80
14	.96	1.15	.72	1.41	1.06
15	.00	.00	.00	.00	.00
16	.00	.00	--	.00	.00
17	.00	.00	--	.00	.00
18	.00	.00	--	.00	.00
19	.00	.00	--	.00	.00
20	.00	.00	--	.00	.00
21	.00	.00	--	.00	.00
22	.05	.09	--	.09	.08
23	.00	.00	--	.00	.00
24	.00	.00	--	.00	.00
25	.02	.04	--	.00	.02
26	.00	.05	--	.08	.04
27	.00	.00	--	.00	.00
28	.00	.00	--	.00	.00
29	.02	.08	--	.08	.06
30	.00	.00	--	.00	.00
31	.00	.00	--	.00	.00
January 2000					
1	0.01	0.02	--	0.01	0.01
2	.00	.00	--	.01	.00
3	.02	.03	--	.04	.03
4	.42	.47	--	.45	.45
5	.00	.01	--	.01	.01
6	.00	.00	--	.00	.00
7	.00	.00	--	.01	.00
8	.00	.00	--	.00	.00
9	.18	.20	--	.20	.19
10	.03	.03	--	.03	.03

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
January 2000—*Continued*					
11	0.00	0.02	--	0.02	0.01
12	.00	.00	--	.00	.00
13	.02	.02	0.03	.02	.02
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.00	.00	.00	.00	.00
17	.00	.00	.00	.00	.00
18	.00	.00	.00	.00	.00
19	.02	.04	.02	.04	.03
20	.00	.01	.00	.00	.00
21	.00	.00	.00	.01	.00
22	.00	.00	.00	.00	.00
23	.08	.17	.04	.18	.12
24	.00	.00	.00	.00	.00
25	.00	.00	.00	.00	.00
26	.00	.00	.00	.00	.00
27	.00	.00	.00	.00	.00
28	.00	.02	.00	.02	.01
29	.27	.35	.26	.34	.31
30	.15	.21	.15	.19	.18
31	.00	.01	.00	.01	.01
February 2000					
1	0.00	0.01	0.00	0.00	0.00
2	.00	.00	.00	.00	.00
3	.01	.02	.01	.02	.02
4	.01	.00	.00	.00	.00
5	.00	.07	.01	.04	.03
6	.00	.01	.00	.00	.00
7	.00	.00	.00	.00	.00
8	.00	.02	.00	.00	.01
9	.00	.00	--	.01	.00
10	.02	.00	--	.00	.01
11	.04	.04	.03	.04	.04
12	.04	.08	.07	.08	.07
13	.39	.42	.42	.42	.41
14	.56	.56	.57	.56	.56
15	.00	.00	.00	.00	.00

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
February 2000—*Continued*					
16	0.00	0.00	0.00	0.00	0.00
17	.01	.01	.01	.02	.01
18	1.49	1.73	1.60	1.66	1.62
19	.05	.05	.05	.04	.05
20	.00	.01	.00	.01	.01
21	.00	.00	.00	.00	.00
22	.03	.05	.03	.04	.04
23	.00	.00	.00	.00	.00
24	.00	.00	.00	.00	.00
25	.00	.00	.00	.00	.00
26	.00	.00	.00	.00	.00
27	.33	.36	.34	.35	.35
28	.00	.00	.00	.00	.00
29	.00	.00	.00	.00	.00
March 2000					
1	0.02	0.02	0.02	0.02	0.02
2	.00	.00	.00	.00	.00
3	.01	.02	.02	.02	.02
4	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00
6	.00	.00	.00	.00	.00
7	.01	.01	.02	.01	.01
8	.00	.00	.00	.00	.00
9	.33	.30	.20	.19	.26
10	.00	.00	.00	.00	.00
11	.83	.90	.90	.92	.89
12	.01	.02	.00	.02	.01
13	.00	.00	.00	.00	.00
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.33	.37	.36	.39	.36
17	.10	.16	.11	.15	.13
18	.00	.00	.00	.00	.00
19	.00	.00	.00	.00	.00
20	.48	.51	.49	.47	.49

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
			March 2000—*Continued*		
21	0.08	0.08	0.08	0.09	0.08
22	.00	.00	.00	.00	.00
23	.00	.00	.00	.00	.00
24	.00	.00	.00	.00	.00
25	.02	.03	.05	.03	.03
26	.00	.00	.00	.00	.00
27	.03	.04	.05	.06	.05
28	.09	.10	.12	.08	.10
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
31	.00	.00	.00	.00	.00
			April 2000		
1	0.00	0.00	0.00	0.00	0.00
2	.00	.00	.00	.01	.00
3	.73	.81	.76	.78	.77
4	.49	.55	.51	.54	.52
5	.00	.00	.00	.00	.00
6	.00	.00	.00	.00	.00
7	.00	.00	.00	.00	.00
8	.60	.68	.65	.69	.66
9	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00
\11	.26	.27	.26	.29	.27
12	.05	.09	.06	.08	.07
13	.01	.01	.01	.02	.01
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.00	.00	.00	.00	.00
17	.33	.39	.42	.47	.40
18	.08	.12	.09	.10	.10
19	.01	.01	.01	.01	.01
20	.06	.07	.09	.10	.08
21	.39	.41	.40	.43	.41
22	.07	.10	.07	.10	.09
23	.00	.00	.00	.00	.00
24	.41	.45	.43	.44	.43
25	.31	.33	.33	.33	.33

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
April 2000—*Continued*					
26	0.00	0.00	0.00	0.00	0.00
27	.00	.00	.00	.00	.00
28	.00	.00	.00	.00	.00
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
May 2000					
1	0.05	0.08	0.06	0.08	0.07
2	.18	.20	.18	.19	.19
3	.00	.00	.00	.00	.00
4	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00
6	.00	.00	.00	.00	.00
7	.00	.00	.00	.00	.00
8	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00
11	.00	.00	.00	.00	.00
12	.13	.02	.01	.01	.04
13	.62	.74	.64	.69	.67
14	.00	.01	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.01	.02	.01	.02	.02
17	.05	.06	.05	.05	.05
18	.00	.00	.00	.00	.00
19	.94	1.03	.90	1.01	.97
20	.04	.05	.05	.05	.05
21	.04	.05	.06	.06	.05
22	.00	.00	.00	.00	.00
23	.73	.76	.80	.78	.77
24	.00	.00	.00	.00	.00
25	.01	.02	.02	.03	.02
26	.00	.00	.00	.00	.00
27	1.69	1.97	1.99	2.21	1.97
28	.03	.04	.03	.03	.03
29	.02	.03	.04	.06	.04
30	.00	.00	.00	.00	.00
31	.00	.00	.00	.00	.00

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
June 2000					
1	0.00	0.00	0.00	0.00	0.00
2	.05	.06	.07	.07	.06
3	.01	.02	.02	.04	.02
4	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00
6	.02	.03	.02	.02	.02
7	.00	.00	.00	.00	.00
8	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00
11	.00	.00	.00	.00	.00
12	.00	.00	.00	.00	.00
13	.00	.00	.00	.00	.00
14	.10	.13	.19	.17	.15
15	.56	.67	.66	.74	.66
16	.00	.00	.00	.00	.00
17	1.61	1.73	1.51	1.43	1.57
18	.67	.73	.66	.73	.70
19	.34	.33	.34	.32	.33
20	.32	.30	.23	.26	.28
21	1.52	1.67	1.59	1.71	1.62
22	.15	.15	.15	.15	.15
23	.00	.00	.00	.00	.00
24	.00	.00	.00	.00	.00
25	.15	.18	.11	.17	.15
26	.10	.11	.11	.12	.11
27	.33	.32	.29	.31	.31
28	.19	.19	.19	.19	.19
29	.00	.01	.01	.01	.01
30	.00	.00	.00	.00	.00
July 2000					
1	0.00	0.00	0.00	0.00	0.00
2	.00	.00	.00	.00	.00
3	.55	.70	.70	.75	.68
4	.16	.13	.15	.18	.16
5	.07	.08	.08	.11	.09

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
July 2000—*Continued*					
6	0.02	0.02	0.02	0.01	0.02
7	.00	.00	.00	.00	.00
8	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00
10	1.62	1.64	--	1.45	1.57
11	.23	.38	--	.51	.37
12	.00	.00	--	.00	.00
13	.00	.00	--	.00	.00
14	--	.93	--	.76	.85
15	--	.00	--	.00	.00
16	--	.12	--	.07	.10
17	--	.01	--	.00	.01
18	--	.00	--	.00	.00
19	--	.69	--	.70	.70
20	--	.01	--	.01	.01
21	--	.00	--	.00	.00
22	--	.00	--	.00	.00
23	--	.00	--	.00	.00
24	--	.12	--	.04	.08
25	--	.00	--	.00	.00
26	--	.00	--	.00	.00
27	--	.00	--	.00	.00
28	--	.17	--	.15	.16
29	--	.49	--	.52	.51
30	--	.02	--	.02	.02
31	--	.08	--	.07	.08
August 2000					
1	--	0.51	--	0.66	0.59
2	--	.01	--	.01	.01
3	--	.07	--	.05	.06
4	--	.00	--	.00	.00
5	--	.00	--	.00	.00
6	--	.01	--	.00	.01
7	--	.75	--	.78	.77
8	--	.82	--	.78	.80
9	--	.71	--	.70	.71
10	--	.13	--	.14	.14

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
August 2000—*Continued*					
11	--	0.00	--	0.00	0.00
12	--	.00	--	.00	.00
13	--	.00	--	.00	.00
14	--	.00	--	.00	.00
15	--	.00	--	.00	.00
16	--	.00	--	.00	.00
17	--	.01	--	.01	.01
18	--	.35	--	.35	.35
19	--	.00	--	.00	.00
20	--	.00	--	.00	.00
21	--	.00	--	.00	.00
22	--	.00	--	.00	.00
23	--	.00	--	.00	.00
24	--	.23	--	.24	.24
25	0.00	.00	0.00	.00	.00
26	.00	.00	.00	.00	.00
27	.52	.54	.58	.54	.55
28	.01	.00	.00	.01	.01
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
31	.00	.00	.00	.00	.00
September 2000					
1	0.02	0.02	0.02	0.20	0.07
2	--	.38	.38	.26	.34
3	--	.01	.01	.01	.01
4	--	.12	.11	.22	.15
5	--	.00	.00	.00	.00
6	--	.00	.00	.00	.00
7	--	.00	.00	.00	.00
8	--	.00	.00	.00	.00
9	--	.00	.00	.00	.00
10	--	1.08	.90	.84	.94
11	--	.00	.02	.03	.02
12	--	.00	.00	.01	.00
13	--	.00	.00	.00	.00
14	--	.02	.01	.01	.01
15	--	.02	.01	.02	.02

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
September 2000—*Continued*					
16	--	0.00	0.00	0.00	0.00
17	--	.00	.00	.00	.00
18	--	.00	.00	.00	.00
19	--	.00	.00	.00	.00
20	--	.00	.00	.00	.00
21	--	.15	.16	.18	.16
22	--	.01	.00	.01	.01
23	--	.00	.02	.01	.01
24	--	.16	.16	.17	.16
25	--	.95	.96	.94	.95
26	--	.05	.03	.05	.04
27	--	.00	.00	.00	.00
28	--	.01	.02	.01	.01
29	0.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
October 2000					
1	0.00	0.00	0.00	0.00	0.00
2	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00
4	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00
6	.00	.05	.05	.06	.04
7	.00	.00	.00	.00	.00
8	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00
11	.00	.00	.00	.00	.00
12	.00	.00	.00	.00	.00
13	.00	.00	.00	.00	.00
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.00	.00	.00	.00	.00
17	--	.42	.43	.44	.43
18	--	.07	.07	.07	.07
19	--	.00	.00	.00	.00
20	--	.00	.00	.00	.00

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
			October 2000—*Continued*		
21	--	0.00	0.00	0.00	0.00
22	--	.01	.02	.00	.01
23	--	.00	.00	.00	.00
24	--	.00	.00	.00	.00
25	--	.00	.00	.00	.00
26	--	.03	.00	.00	.01
27	--	.00	.00	.00	.00
28	--	.00	.00	.00	.00
29	--	.00	.00	.00	.00
30	--	.00	.00	.00	.00
31	--	.00	.00	.00	.00
			November 2000		
1	--	0.00	0.00	0.00	0.00
2	--	.00	.00	.00	.00
3	--	.00	.00	.00	.00
4	--	.00	.00	.00	.00
5	--	.00	.00	.00	.00
6	--	.00	.00	.00	.00
7	--	.12	.08	.11	.10
8	--	.05	.05	.06	.05
9	--	.58	.52	.59	.56
10	--	.00	.00	.00	.00
11	--	.00	.00	.00	.00
12	--	.00	.00	.00	.00
13	--	.07	.06	.08	.07
14	--	.00	.00	.00	.00
15	--	.00	.00	.00	.00
16	--	.01	.00	.01	.01
17	--	.00	.00	.00	.00
18	--	.00	.00	.00	.00
19	--	.00	.00	.00	.00
20	--	.07	.02	.06	.05
21	--	.00	.00	.00	.00
22	--	.00	.00	.00	.00
23	--	.00	.00	.00	.00
24	--	.00	.00	.00	.00
25	--	.18	.16	.21	.18

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
November 2000—*Continued*					
26	--	0.06	0.08	0.08	0.07
27	--	.00	.00	.00	.00
28	--	.00	.00	.00	.00
29	--	.09	.05	.09	.08
30	--	.00	.00	.00	.00
December 2000					
1	--	0.03	0.03	0.04	0.03
2	--	.03	.01	.03	.02
3	--	.00	.00	.00	.00
4	--	.00	.00	.00	.00
5	--	.00	.00	.00	.00
6	--	.00	.00	.00	.00
7	--	.00	.00	.00	.00
8	--	.00	.00	.00	.00
9	--	.00	.00	.00	.00
10	--	.11	.09	.11	.10
11	--	.01	.01	.01	.01
12	--	.00	.01	.00	.00
13	--	1.19	1.15	1.17	1.17
14	--	.26	.24	.27	.26
15	--	.00	.00	.00	.00
16	--	.48	.45	.48	.47
17	--	.33	.32	.33	.33
18	--	.00	.00	.01	.00
19	--	.00	.01	.00	.00
20	--	.00	.00	.00	.00
21	--	.01	.00	.05	.02
22	--	.00	.00	.00	.00
23	--	.01	.00	.00	.00
24	--	.03	.00	.01	.01
25	--	.00	.00	.00	.00
26	--	.01	.00	.00	.00
27	--	.00	.00	.00	.00
28	--	.00	.00	.01	.00
29	--	.00	.00	.00	.00
30	--	.00	.00	.00	.00
31	--	.00	.00	.00	.00

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
January 2001					
1	--	0.00	0.00	0.00	0.00
2	--	.00	.00	.00	.00
3	--	.02	.00	.00	.01
4	--	.12	.02	.18	.11
5	--	.00	.00	.00	.00
6	--	.00	.00	.00	.00
7	--	.00	.00	.00	.00
8	--	.01	.00	.01	.01
9	--	.00	.00	.00	.00
10	--	.00	.00	.01	.00
11	--	.00	.00	.00	.00
12	--	.00	.00	.00	.00
13	--	.00	.00	.00	.00
14	--	.00	.00	.00	.00
15	--	.00	.00	.00	.00
16	--	.00	.00	.00	.00
17	--	.00	.00	.00	.00
18	--	.26	.26	.27	.26
19	--	1.53	1.44	1.56	1.51
20	--	.02	.00	.01	.01
21	--	.09	.00	.11	.07
22	--	.07	.06	.04	.06
23	--	.00	.00	.00	.00
24	--	.00	.00	.00	.00
25	--	.00	.00	.00	.00
26	--	.00	.00	.00	.00
27	--	.04	.03	.05	.04
28	--	.00	.00	.00	.00
29	--	.21	.17	.21	.20
30	--	.17	.17	.19	.18
31	--	.06	.04	.05	.05
February 2001					
1	--	0.00	0.00	0.01	0.00
2	--	.02	.01	.02	.02
3	--	.00	.00	.01	.00
4	--	.00	.00	.00	.00
5	--	.02	.00	.02	.01

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
February 2001—*Continued*					
6	--	0.03	0.02	0.03	0.03
7	--	.00	.00	.00	.00
8	--	.00	.00	.00	.00
9	--	.29	.27	.29	.28
10	--	.00	.00	.01	.00
11	--	.00	.00	.00	.00
12	--	.00	.00	.00	.00
13	--	.01	.01	.01	.01
14	--	.43	.41	.43	.42
15	--	.37	.33	.38	.36
16	--	.90	.90	.91	.90
17	--	.00	.00	.00	.00
18	--	.00	.00	.00	.00
19	--	.00	.00	.00	.00
20	--	.00	.00	.00	.00
21	--	.00	.00	.00	.00
22	--	.09	.05	.12	.09
23	--	.00	.05	.01	.02
24	--	.00	.00	.00	.00
25	--	.10	.10	.11	.10
26	--	.00	.00	.00	.00
27	--	.00	.00	.00	.00
28	--	.06	.04	.07	.06
March 2001					
1	--	0.00	0.00	0.00	0.00
2	--	.07	.06	.07	.07
3	--	.00	.00	.00	.00
4	--	.39	.31	.40	.37
5	--	.11	.01	.07	.06
6	--	.04	.00	.06	.03
7	--	.04	.00	.04	.03
8	--	.03	.00	.00	.01
9	--	.00	.00	.00	.00
10	--	.00	.00	.00	.00
11	--	.00	.00	.00	.00
12	--	.34	.32	.37	.34
13	--	.21	.13	.16	.17
14	--	.00	.00	.00	.00
15	--	.35	.34	.39	.36

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
March 2001—*Continued*					
16	--	0.05	0.04	0.05	0.05
17	--	.01	.02	.02	.02
18	--	.00	.00	.00	.00
19	--	.00	.00	.00	.00
20	--	.03	.03	.04	.03
21	--	.43	.40	.46	.43
22	--	.04	.02	.04	.03
23	--	.00	.00	.00	.00
24	--	.07	.07	.06	.07
25	--	.00	.00	.00	.00
26	--	.00	.00	.00	.00
27	--	.00	.00	.00	.00
28	--	.00	.00	.00	.00
29	--	.71	.67	.70	.69
30	--	.08	.08	.08	.08
31	--	.00	.00	.00	.00
April 2001					
1	--	0.35	0.30	0.36	0.34
2	--	.00	.00	.00	.00
3	--	.19	.17	.19	.18
4	--	.00	.00	.01	.00
5	--	.00	.00	.00	.00
6	--	.18	.16	.19	.18
7	--	.00	.00	.00	.00
8	--	.00	.00	.00	.00
9	--	.00	.00	.00	.00
10	--	.02	.02	.02	.02
11	--	.00	.00	.00	.00
12	--	.00	.01	.01	.01
13	--	.32	.30	.34	.32
14	--	.00	.00	.00	.00
15	--	.05	.04	.06	.05
16	--	.00	.00	.00	.00
17	--	.27	.07	.29	.21
18	--	.02	.02	.02	.02
19	--	.00	.00	.00	.00
20	--	.01	.01	.01	.01

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
			April 2001—*Continued*		
21	--	0.11	0.08	0.11	0.10
22	--	.00	.00	.00	.00
23	--	.00	.00	.00	.00
24	--	.16	.13	.16	.15
25	--	.00	.00	.00	.00
26	--	.00	.00	.00	.00
27	--	.00	.00	.00	.00
28	--	.00	.00	.00	.00
29	--	.00	.00	.00	.00
30	--	.00	.00	.00	.00
			May 2001		
1	--	0.07	0.02	0.01	0.03
2	--	.00	.00	.00	.00
3	--	.00	.00	.00	.00
4	--	.00	.00	.00	.00
5	--	.00	.00	.00	.00
6	--	.00	.00	.00	.00
7	--	.00	.00	.00	.00
8	--	.04	.04	.05	.04
9	--	.00	.00	.00	.00
10	--	.00	.00	.00	.00
11	--	.00	.00	.00	.00
12	--	.01	.01	.01	.01
13	--	.00	.00	.00	.00
14	--	.00	.00	.00	.00
15	0.34	.49	.45	.46	.44
16	1.01	1.47	1.53	1.46	1.37
17	.66	.87	.91	.81	.81
18	1.14	2.08	1.91	2.10	1.81
19	.37	.58	.51	.50	.49
20	.01	.01	.00	.00	.01
21	.27	.48	.57	.45	.44
22	.51	.95	1.02	.98	.86
23	.00	.01	.01	.00	.01
24	.75	.34	.99	.31	.60
25	.00	.01	.00	.01	.01

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
May 2001—*Continued*					
26	0.00	0.00	0.00	0.00	0.00
27	.18	.24	.21	.22	.21
28	.00	.00	.00	.00	.00
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
31	.00	.00	.00	.00	.00
June 2001					
1	0.03	0.07	0.08	0.12	0.08
2	.21	.28	.28	.28	.26
3	.00	.00	.01	.00	.00
4	.26	.35	.36	.34	.33
5	.18	.26	.21	.24	.22
6	1.26	1.58	1.90	1.51	1.56
7	.04	.07	.08	.06	.06
8	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00
11	.00	.00	.00	.00	.00
12	.00	.00	.00	.00	.00
13	.00	.00	.00	.00	.00
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.04	.14	.14	.14	.12
17	.00	.00	.00	.00	.00
18	.00	.00	.00	.00	.00
19	.00	.00	.00	.00	.00
20	.00	.00	.00	.00	.00
21	.00	.00	.00	.00	.00
22	.16	.30	.29	.30	.26
23	.20	.27	.41	.22	.28
24	.00	.01	.00	.00	.00
25	.04	.07	.07	.09	.07
26	.06	.10	.08	.11	.09
27	.00	.00	.00	.00	.00
28	.00	.00	.00	.00	.00
29	.22	.33	.13	.42	.28
30	.04	.07	.13	.13	.09

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
July 2001					
1	0.22	0.28	0.03	0.27	0.20
2	.00	.00	.04	.00	.01
3	.00	.01	.02	.01	.01
4	.36	.52	.01	.50	.35
5	.09	.06	.02	.00	.04
6	.00	.00	.04	.00	.01
7	.00	.00	.04	.00	.01
8	.77	.86	.22	.74	.65
9	.00	.00	.07	.00	.02
10	.00	.00	.04	.00	.01
11	.00	.00	.03	.00	.01
12	.00	.00	.00	.00	.00
13	.00	.00	.00	.00	.00
14	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00
16	.00	.00	.00	.00	.00
17	.81	.98	.91	.76	.87
18	.01	.05	.03	.05	.04
19	.00	.00	.00	.00	.00
20	.00	.00	.00	.00	.00
21	.00	.00	.00	.00	.00
22	.55	.53	.46	.43	.49
23	.00	.00	.00	.00	.00
24	.00	.00	.00	.00	.00
25	.00	.00	.00	.00	.00
26	2.91	3.18	3.49	3.06	3.16
27	.00	.00	.00	.01	.00
28	1.33	1.43	1.38	1.49	1.41
29	.94	1.09	1.10	1.07	1.05
30	.00	.00	.00	.00	.00
31	.00	.00	.00	.00	.00
August 2001					
1	0.00	0.00	0.00	0.00	0.00
2	.00	.00	.00	.00	.00
3	.16	.27	.54	.35	.33
4	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
August 2001—*Continued*					
6	0.00	0.00	0.00	0.00	0.00
7	.03	.05	.08	.05	.05
8	.00	.00	.00	.01	.00
9	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00
11	.00	.00	.00	.00	.00
12	.89	1.16	.77	1.00	.96
13	.39	.32	.38	.46	.39
14	.00	.00	.00	.01	.00
15	.00	.00	.00	.00	.00
16	.02	.04	.03	.03	.03
17	.00	.01	.00	.01	.01
18	.00	.00	.00	.00	.00
19	.02	.02	.03	.05	.03
20	.00	.00	.00	.00	.00
21	.00	.00	.00	.00	.00
22	.00	.00	.00	.00	.00
23	.78	.93	.95	.87	.88
24	.00	.00	.00	.00	.00
25	.00	.01	.01	.00	.01
26	.00	.00	.00	.00	.00
27	.05	.07	.06	.07	.06
28	.00	.00	.00	.00	.00
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
31	.00	.00	.00	.00	.00
September 2001					
1	0.42	0.51	0.46	0.59	0.50
2	--	.00	.00	.00	.00
3	--	.36	.61	.72	.56
4	--	.00	.00	.00	.00
5	--	.00	.00	.01	.00
6	--	.00	.00	.00	.00
7	--	.00	.00	.00	.00
8	--	.00	.00	.00	.00
9	--	.00	.00	.00	.00
10	--	.01	.01	.01	.01

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
September 2001—*Continued*					
11	--	0.01	0.50	0.01	0.17
12	--	.00	.00	.00	.00
13	--	.00	.00	.00	.00
14	--	.00	.00	.00	.00
15	--	.00	.00	.00	.00
16	--	.00	.00	.00	.00
17	--	.00	.00	.00	.00
18	--	.00	.00	.00	.00
19	--	.00	.00	.00	.00
20	--	.25	.20	.25	.23
21	--	.00	.00	.00	.00
22	--	.00	.00	.00	.00
23	--	.00	.00	.00	.00
24	--	.74	.65	.74	.71
25	--	.18	.13	.18	.16
26	--	.00	.00	.00	.00
27	--	.00	.00	.00	.00
28	--	.00	.00	.00	.00
29	--	.00	.00	.00	.00
30	--	.00	.00	.00	.00
October 2001					
1	--	0.00	0.00	0.00	0.00
2	--	.00	.00	.00	.00
3	--	.00	.00	.00	.00
4	--	.00	.00	.00	.00
5	--	.00	.00	.00	.00
6	--	.34	.28	.34	.32
7	--	.00	.00	.00	.00
8	--	.00	.00	.00	.00
9	--	.00	.00	.00	.00
10	--	.00	.00	.00	.00
11	--	.00	.00	.00	.00
12	--	.19	.15	.19	.18
13	--	.00	.00	.00	.00
14	--	.36	.35	.36	.36
15	--	.00	.00	.00	.00
16	--	.15	.13	.15	.14
17	--	.00	.00	.00	.00
18	--	.00	.00	.00	.00
19	--	.00	.00	.00	.00
20	--	.00	.00	.00	.00

Table 4. Daily precipitation, in inches, in the Ballard Fork Watershed, West Virginia, November 1999–November 2001—*Continued*

Date	Sally Fork Mountaintop (380409081545001)	Sally Fork Valley (380406081551701)	Left Fork Mountaintop (380423081553001)	Spring Branch Valley (380406081561701)	Average
October 2001—*Continued*					
21	--	0.00	0.00	0.00	0.00
22	--	.00	.00	.00	.00
23	--	.00	.00	.00	.00
24	--	.00	.00	.00	.00
25	--	.31	.23	.35	.30
26	--	.00	.00	.00	.00
27	--	.00	.00	.00	.00
28	--	.00	.00	.00	.00
29	--	.00	.00	.00	.00
30	--	.00	.00	.00	.00
31	--	.00	.00	.00	.00
November 2001					
1	--	0.00	0.00	0.00	0.00
2	--	.01	.00	.01	.01
3	--	.26	.25	.25	.25
4	--	.00	.00	.00	.00
5	--	.00	.00	.00	.00
6	--	.00	.00	.00	.00
7	--	.00	.00	.00	.00
8	--	.01	.01	.01	.01
9	--	.00	.00	.00	.00
10	--	.00	.00	.00	.00
11	--	.00	.00	.00	.00
12	--	.00	.00	.00	.00
13	--	.00	.00	.03	.01
14	--	.00	.00	.00	.00